THE WONDER & THE GLORY OF THE STARS

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THE WONDER & THE GLORY OF THE STARS

By

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PREFACE

THIS volume of astronomical sketches is the outcome of nearly two hundred distinct lectures delivered during the last twenty-two years, under the David Elder Foundation, at the Royal Technical College, Glasgow. The guiding motive throughout each course of lectures was to familiarize the audience with the heavenly bodies, by knowing how to recognize the stars and constellations, and delighting in the wonderful discoveries associated with the name of each. In fact, the lecturer looked upon himself as a tourist-guide in a series of excursions over various parts of the heavens.

A careful selection from these lectures was published in *Chambers's Journal*; and these, with some additions to the text, and illustrations, are now brought together. They do not aim at teaching the whole subject of astronomy, but rather at increasing the enjoyment and the wonder felt by everyone on a starry night, with all "the glory and the freshness of a dream"; and they aim occasionally at putting things in a new setting which may be of interest to astronomers. While enjoying to the full the speculative hypotheses that are in vogue to-day, the author warns his readers against giving the same credence to such flights of the imagination as would be gratefully given to the contributions of those who have laid the solid foundations of Astronomy, the Queen of the Sciences.

The whole of this series of articles is interdependent, yet each one is self-contained. This arrangement necessarily involves some repetition, but only of matters so important in their application that the reader may be glad to have his attention directed to them more than once.

The last two chapters differ essentially from the first fifteen. They form a self-contained account of present-day speculation on the Origin of the Universe.

After this preface I must insert two wonderful ancient parallel poems, both of them expressing identically, and most beautifully, the emotions felt by most of us on a brilliant starry night. They were handed to me, as being interesting from their similarity, by the late Mr Humphry Ward, shortly before his death.

GEORGE FORBES.

THE SHED, PITLOCHRIE,
July 1926.

THE WONDER AND THE GLORY OF THE STARS

When I consider the heavens, the work of thy fingers, the moon and the stars, which thou hast ordained;

What is man, that thou art mindful of him? and the son of man, that thou visitest him?

Thou hast made him a little lower than the angels, and hast crowned him with glory and honour.

Thou madest him to have dominion over the works of thy hands; thou hast put all things under his feet.

Psalm viii., *The Psalmist*

Οἶδ' ὅτι θνατος ἐγω και ἐφαμερος· ἀλλ' ὅταν ἀστρων
Μαστευω πυκινας ἀμφιδρόμους ἑλικας
Οὐκετ' ἐπιψαυω γαιης ποσιν, ἀλλα παρ' αὐτῳ
Ζανι θεωτρεφεος πιμπλαμαι ἀμβροσης.

Claudius Ptolemæus the Astronomer,
circa A.D. 180

Quoted in *Mackail's Anthology*, iv. 32. Mackail's translation is as follows:—

"I know that I am mortal and ephemeral; but when I scan the multitudinous circling spirals of the stars, no longer do I touch earth with my feet, but sit with Zeus himself, and take my fill of the ambrosial food of gods."

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CHAPTER I

HOW TO KNOW THE STARS

I

When the Christmas party breaks up at midnight, and we file out from the porch into the frosty air on this moonless night, the stars are shining upon the dry, crisp snow in the fields; and a general exclamation directs our attention to an altered aspect, as we remark in chorus: "What a glorious night!"

And who can wonder that the same thought strikes the soul of one and all? For Orion, the Hunter, the most magnificent constellation in the heavens, his limbs pricked out in sparkling gems, stands facing us in the south. And he is surrounded, enframed, by an arch of diamond-stars including six of the brightest jewels in the whole heavens.

This is a notable fact worth remembering, that at midnight during Christmastide—that is to say, in December—the grandest and most impressive grouping of stars that exists in either hemisphere stands forth, filling the southern sky up to the zenith overhead, kindling in every heart those feelings of love, awe, wonder and admiration to which it is already tuned by traditions and associations of the happiest and merriest festival of the year.

Nor can we fail to notice the Milky Way, that pale white, gauze-like veil passing diagonally over the left side of the picture, a band of soft light shining along with the stars upon a snow-clad earth. The complete picture cries out to be fixed in our memory. It appeals to all; to the children fresh from their games as much as to grandparents, reminiscent of past Christmases, when they were young. They are all spell-bound, on such a night as this, with wonder and admiration.

The philosopher is conscious of the hand of God upon the orbs of night. The musician hears, as from a soft-toned violin, the music of the spheres. The poet's soul yearns to give expression to his insight about events that may be happening in those distant spaces. The artificer feels in this vision of new worlds that his own work assumes a different value. Even the staid merchant or stockbroker assures himself that money is not the only God he worships.

This love for the glory of the heavens is no modern craze. It has always been a passion of the human soul. In the days of the prophets, when Job was extolling the powers of the Creator, nothing appealed to him more firmly than the fact that it was He "which maketh Arcturus, Orion and Pleiades, and the chambers of the south; which doeth great things past finding out; yea, and wonders without number."

While we gaze at the glorious picture of Orion, set in a frame of brightest stars, Sirius and Procyon, Castor and Pollux, Capella, Aldebaran and the Pleiades, each man or child does unconsciously add, or put into the picture, "the glory and the freshness of a dream," "with new-fledged hope still fluttering in his breast," while he seems to be "moving about in worlds not realized—high instincts."

The great poet tells us that these unexpressed, inexpressible upliftings underlying the picture in our souls—these dim instincts of exaltation—do assure us, at such moments, that "our souls have sight of that immortal sea which brought us hither," and this exaltation goes far to account for the universal yearning to know something about the stars, or, at the very least, to know their names. That yearning is universal. Millions of men and women share the regret of Thomas Carlyle when he said: "Why did not somebody teach me the constellations, and make me at home in the starry heavens which are always overhead, and which I don't half know to this day?"

II

On such a night we feel ourselves to be pygmies in presence of that multitude of stars. Their number, their incredible distance from us, and the purpose they serve in those distant realms of space stupefy us. And the more we learn from the hard facts of observation the greater is the wonder and the glory.

It may seem incredible that the number of stars visible at any one time to the unaided eye never exceeds two or three thousand; but this is true. And yet the smallest telescope adds enormously to the number. In the year 1610 Galileo for the first time pointed his little telescope to the white streak we call the Milky Way, and discovered in a moment the wonderful truth that its light comes

from millions of minute stars, which his glass revealed for the first time.

In 1846 Lord Rosse made and erected in Ireland a huge telescope, six feet in diameter. His gigantic telescope revealed the fact, originally suspected by Sir William Herschel, that in all probability the universe of stars, to the number of thousands of millions, filling our outlook at night, may be but a sample of millions of other universes of stars, each of these universes appearing in the telescope as a minute nebulous star.

That telescope remained the largest ever made until, in 1918, another telescope of seventy-two inches in diameter, of a splendid construction, was erected at Victoria, in British Columbia. Since then Professor George Hale has had completed, at Mount Wilson in California, the premier telescope of the world, one hundred inches in diameter. These great reflecting telescopes present to our inspection stars to the number of hundreds of millions. Photography, moreover, can, by prolonged exposure of a plate in the focus of a gigantic telescope, depict upon it stars that cannot be seen by human eyes assisted by the most powerful telescope.

Immense as is the number of stars, their distances from us are still more appalling. The human mind cannot conceive them, though expressed in figures derived from accurate measurement. The nearest star of all is, in fact, twenty-six billion miles away. And astronomers are dealing with stars estimated to be tens of thousands of times more distant, while those objects about whose distances we can form no estimate must be immeasurably farther away. Comparatively speaking, the sun and the planets are quite close, the former being only ninety-three million miles from us.

Stupendous as are the figures that tell the number and the distance of the stars, our wonder is increased still more when we learn what the stars are, and the size of them. At first it seems almost incredible that the stars are suns ; and that if they were only ninety-three million miles away, as the sun is, instead of being millions of times farther off, many of them would look just like our sun, some larger, others smaller, than that great orb of light ; some more dazzling in brightness, others less so. If the sun were at the great distance at which we know the nearest star to be, its light would seem to be a hundred thousand million times feebler than it is, and

the sun would then be one of the smallest stars visible to the naked eye.

The years 1920 and 1921 will ever be memorable as the dates when the astronomers at Mount Wilson, by means of a beautifully ingenious optical device, succeeded in measuring the diameters of two stars, Betelgeuse in the right shoulder of Orion, and Arcturus. Both of these stars belong to a small and exceptional class, already suspected to be vastly larger than the sun or other stars. It was found, in 1920, that, if the centre of Betelgeuse were in the place where the sun's centre is, then its spherical surface would *probably* envelop the whole of the earth's orbit and extend nearly to Mars. In 1921 it was found that *certainly* the diameter of Arcturus is about nineteen million miles, the sun's diameter being only eight hundred and sixty-four thousand miles. The difference as to our degree of certainty in the two cases lies in the degree of accuracy with which we know the distances of these two stars.

III

All this time we are supposed to be staring at the constellation of Orion. The principal constellations are, doubtless, known to many readers of these lines. But if they desire to tell a friend what to look for, a useful hint may now be given how best to do this.

When I was a child our father used to amuse us with a pretty game. We were asked to make five pencil-dots upon a piece of paper, and then he would ingeniously join the dots by lines to trace the figure of a man in some queer attitude. Such a game was played by the ancient astronomers. They marked dots upon paper, showing the places of a group of stars, and joined them by lines, or drew a picture on their framework, generally to represent some mythological character, such as Perseus and Andromeda, the twins Castor and Pollux, Orion the Hunter and his dogs, the Bull, the Lion, and so on. In old days these figures were used for describing, say, the position of a comet: "on the right knee of Hercules," "at the mouth of the water-pot in Aquarius," "in the sword of Orion," and the like. We now discard such poetic imagery, and fix positions in the heavens, as we do on the earth, by longitude and latitude. Yet, constellations are still useful upon maps of the heavens, just

as countries are upon maps of the earth, for rough indications of the locality of a star, or a town.

Now, to describe Orion, you mark upon paper five dots like a St Andrew's Cross, or like the five of diamonds. Then draw a man's figure with the two top dots for his shoulders, and the two bottom dots for his feet. The middle dot is his waist, which we mark by three dots nearly horizontal, where three stars are. Add to this a head which, in the heavens, is shown by a few small stars. Now you have a complete man, and, after adding to the waist-girdle a sword-scabbard pointing downwards, to represent a line of small stars, you have an excellent rough picture of the stars that make up the constellation Orion (Fig. 1).

This hint will not have been in vain if it leads a single reader who wants to know the stars to take out into the starlight any winter evening such a rough picture, and compare it with the grand constellation in the southern sky. (In December at midnight, in January at 10 P.M., in February at 8 P.M., Orion is upright in the south.) He can then improve his sketch, and add to it, in proper place, the six brilliant stars that frame Orion in an arch.

The first correction might be to make the three stars of Orion's belt incline a little downwards to the left, pointing to a great bright star at the foot of the arched frame of stars round Orion. This particular star is Sirius, the Dog-star, the brightest star in the whole heavens, and the nearest to us of all the stars visible in our latitude. This pointing of three stars in Orion's belt to the star in the East, Sirius the lord of the stars, deserves special notice because Alphonse Daudet tells us that in Provence the three stars go by the name of "les trois rois"—the three kings.

In the other direction these three stars of Orion's belt point upwards to the right, not very exactly, to another bright star, ruddy in colour, called Aldebaran, in the constellation Taurus, the Bull.

Your picture now includes these two splendid stars, Sirius and Aldebaran, one on each side, at the base of the arched frame of brilliant stars surrounding Orion. The four others must now be named.

Above Sirius no one can fail to notice another solitary white star. This is Procyon, in the Little Dog (*Canis Minor*). Then, following the left part of the arch upwards, you will see a bright pair

of stars still higher in the sky, Castor and Pollux, the Twins (*Gemini*).

The last of the six first-magnitude stars surrounding Orion is Capella, nearly overhead to us in this country at the season and the hour referred to. The figure of Orion points up to it. So does Orion's sword. So also does a line drawn from the middle of the belt through the little stars that make Orion's head. This line,

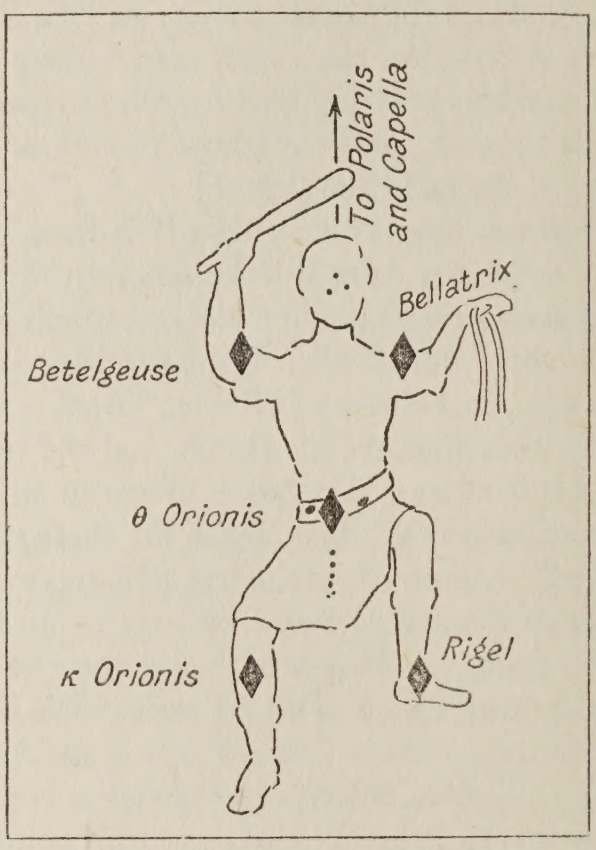

FIG. 1.—The Five of Diamonds transformed into Orion the Hunter, with his belt and sword-scabbard

if carried beyond Capella, goes straight for Polaris, the Pole-star, round which the whole vault of heaven, with all the stars, seems to rotate once in twenty-four hours less four minutes.

Already, in a single night, anyone who knew none of the stars may now have made the acquaintance of all the stars in Orion, of Sirius and Procyon in the Great and Little Dogs (*Canis Major* and *Canis Minor*), of Castor and Pollux in the Twins (*Gemini*), of Capella, the chief star in the Charioteer (*Auriga*), and of Aldebaran, the ruddy ruler of the Bull (*Taurus*), as well as the Pole-star,

Polaris of the Little Bear (*Ursa Minor*). And beside Aldebaran you can see a V-shaped string of faint stars, the Hyades, and beyond them the beautiful "cluster" called the Pleiades.

One single evening with a pencil and paper will, let us hope, have awakened in some readers of these words a new sense of friendship with many stars.

All of the stars (except those which are near to the Pole, and never set) rise, as the sun does, in the eastern half of the sky, and set in the western half. But they differ from the sun in this, that the sun rises and sets at different points of the horizon as the seasons change. So does the moon. Each star, on the contrary, always rises at one fixed place on the horizon, and sets at another fixed place. Also, the sun is far higher in the southern sky at noon in summer than in winter. Each star, on the contrary, always rises to its own definite altitude in the sky without change, summer or winter. The only exceptions to this are the stars we call "planets" (wanderers), of which five can be seen with the naked eye. All the other stars are called "fixed stars"—an absurd name now that astronomers have learnt that all stars are in motion, though their distance prevents us from detecting the motion without instruments. The stars are so distant that if two of them were a million miles apart they would look like one in a large telescope. And if one star moved a million miles, a large telescope would not enable us to detect it. Long-continued observation reveals the movements when they are large enough.

IV

No one could remain content with the friendship only of Orion and his neighbours. He soon wants to feel that at any hour of any clear night he can find many stars whose acquaintance he has made. He will then get hold of an atlas of the stars, or invest a shilling in some little book like Gall & Inglis's *Easy Guide to the Constellations*, containing pictures of the constellations, and guidance for naming the stars.

But it may be well, in a few words, to tell the secret of doing this, by showing how to draw a key-map of two constellations and three other stars in the northern sky. These stars never set in our

latitude, and for that reason, as they can be seen on any clear night all the year round, they ought to be fixed in the memory. They can all be learnt in a quarter of an hour.

Seven stars, forming the outline of a plough, can always be seen. They form part of the constellation the Great Bear (*Ursa Major*). We call that group of stars the Plough in this country. The two front stars of the ploughshare, as everyone knows, point to the Pole-star. And a line from the middle of the Plough through the Pole-star, if carried on as far again, cuts a group of five stars, lying in the shape of a W, forming the constellation Cassiopeia, or Cassiopeia's Chair.

A line which we may imagine to be drawn at right angles to the other line, and passing through the Pole-star, will direct attention to two bright stars, one on each side. One is Capella, to which the figure of Orion points ; the other is Vega, a lovely steel-blue star in the constellation the Lyre (*Lyra*).

When you face the north, the whole of these stars can be observed, from hour to hour, to rotate round the Pole-star. The direction of rotation is shown by the direction in which the plough would go. It is in the opposite direction to that of the hands of a clock. If you bear in mind the position of Capella as being that towards which the plough is moving, your key-map, which can be carried in the memory, will be of great service (Fig. 2).

If anyone who really cares about the stars desires to recognize them, he could not make a better beginning than by drawing from nature this key-map, and gradually fixing it in his memory, Polaris, the Pole-star, in the centre, and all round it, at nearly equal distances and intervals, Cassiopeia, followed by Capella, the Plough, Vega. That is the order in which the procession circulates round the Pole.

A circle can be drawn round this key-map, with arrow-heads at the circumference pointing to the positions of the principal constellations, as they are gradually learned. Thus, already we should place an arrow pointing outwards from Capella, and marked "Orion." An *Easy Guide*, or a star-atlas, will soon enable a beginner to supply arrows on his key-map for the constellations Taurus, Gemini, Leo, Virgo, Aquila, Cygnus, Pegasus, Andromeda, Perseus, and the bright stars Aldebaran, Rigel (the left leg of

Orion), Betelgeuse (Orion's right shoulder), Sirius, Procyon, Regulus (in the Lion), Spica (in the Virgin), Arcturus, Altair, and so on. That would make a splendid beginning, and the rest would follow naturally.

The key-map can, moreover, be held up and twisted round until

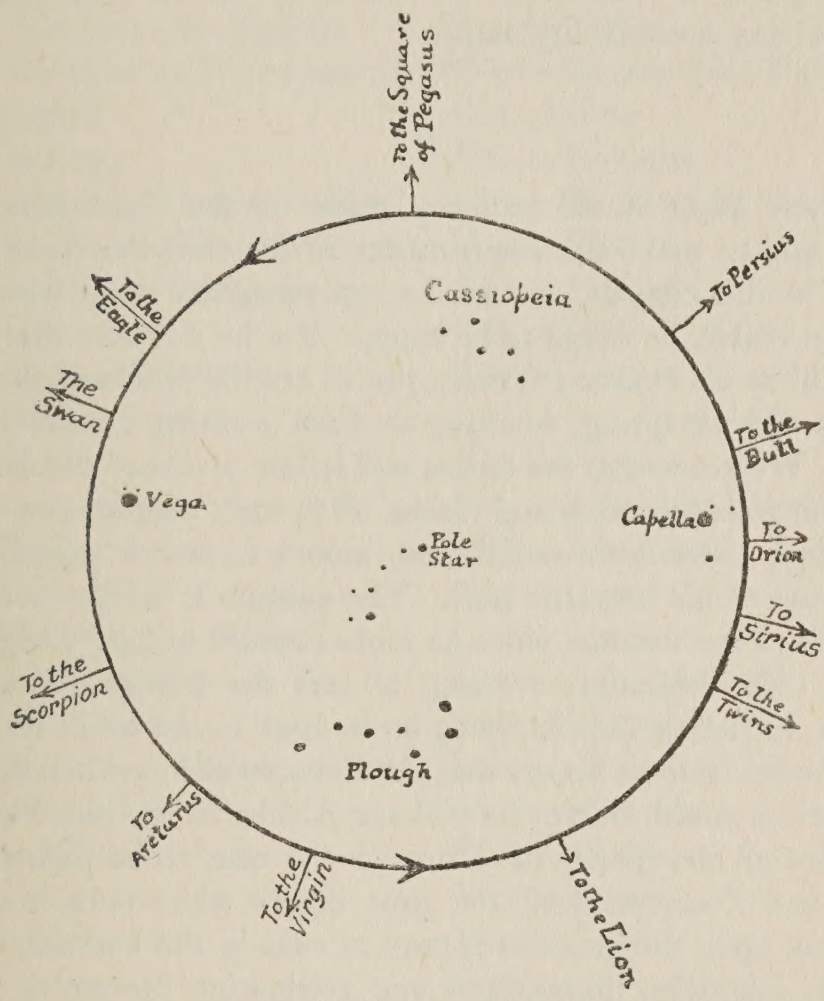

FIG. 2.—Key-map of Circumpolar Stars, rotating nightly round the Pole in the direction shown by arrows

it agrees with the visible northern stars. For example, at midnight in December Capella is above the Pole-star, at the top of the map. Then by giving the key-map a quarter of a turn *forward*, which means *anti-clockwise* or in the opposite direction to the hands of a clock, you will know how the stars will lie, either six hours hence, or at this hour in three months, with the Plough upside down at the top ; twenty-four hours, or twelve months, being represented

by a complete turn of the key-map. Boy Scouts have even learned in this way to tell roughly the time of night, using the key-map and the stars as a clock that can be set for any month. My own Boy Scouts paint the stars of the key-map on the inside of an umbrella. Keeping the stick of the umbrella pointing to the Pole-star, they can twist the umbrella round, to show how the stars are placed at any hour of any month.

V

If these hints should lead any reader to use a star-atlas or a *Guide*, and to make the acquaintance of the stars that have been named in this chapter, so that he can recognize them whenever they are visible, he ought to be happy. For he will find that these stars will be his constant friends, just as are the birds and the wild flowers. In the spring, what joy we have in seeing the first snow-drops ! We know that the crocus will follow, and then the daffodil, and soon after primroses and violets, all in their regular order.

So does a star-lover watch from month to month the majestic procession of his favourite stars. The autumn is to him what the spring is to the botanist, since he looks forward to longer nights of beauty. On September evenings he sees the C-shape of stars in Auriga, including Capella, lying on its back in the north-east, and he rejoices. For he knows that, in a couple of hours hence, or at this hour a month hence, he will see Aldebaran and the Pleiades, and then all the glories of Orion in the east, to be followed by Sirius and Procyon, until the time comes when once more he will look upon the grandest picture of stars in the heavens, Orion erect at midnight, illuminating and celebrating the merry nights of Christmastide.

In the autumn he begins his watch for Aldebaran and the Pleiades, for Orion, for Sirius and Procyon, Castor and Pollux, Capella, his old friends. And he then looks forward with the same feeling of expectation and hope as he always does when he watches for the first blossom of the wild rose, or the flight of the first swallow.

NAMES OF CONSTELLATIONS, WITH THREE-LETTER ABBREVIATIONS OFFICIALLY ADOPTED

And = Andromeda
Ant = Antlia
Aps = Apus
Aql = Aquila (the Eagle)
Aqr = Aquarius (Water-bearer)
Ara = Ara
Arg = Argo
Ari = Aries (the Ram)
Aur = Auriga (Charioteer)
Boo = Boötes (Herdsman)
Cae = Caelum
Cam = Camelopardulus
Cap = Capricornus
Car = Carina
Cas = Cassiopeia
Cen = Centaurus
Cep = Cepheus
Cet = Cetus (the Whale)
Cha = Chamæleon
Cir = Circinus
CMa = Canis Major (Great Dog)
CMi = Canis Minor
Cnc = Cancer (the Crab)
Col = Columba
Com = Coma
CrA = Corona Australis
CrB = Corona (Borealis)
Crt = Crater
Cru = Crux (the Cross)
Cru = Corvus
CVn = Canes Venatici
Cyg = Cygnus (the Swan)
Del = Delphinus
Dor = Dorado
Dra = Draco (the Dragon)
Equ = Equuleus
Eri = Eridanus
For = Fornax
Gem = Gemini (the Twins)
Gru = Grus
Her = Hercules
Hor = Horologium
Hya = Hydra
Hyi = Hydrus
Ind = Indus
Lac = Lacerta
Leo = Leo (the Lion)
Lep = Lepus
Lib = Libra (the Balance)
LMi = Leo Minor
Lup = Lupus
Lyn = Lynx
Lyr = Lyra (the Lyre)
Men = Mensa
Mic = Microscopium
Mon = Monoceros
Mus = Musca
Nor = Norma
Oct = Octans
Oph = Ophiuchus
Ori = Orion (the Hunter)
Pav = Pavo
Peg = Pegasus (Flying Horse
Per = Perseus
Phe = Phœnix
Pic = Pictor
PsA = Piscis Austrinus
Psc = Pisces (the Fishes)
Pup = Puppis

Pyx = Pyxis
Ret = Reticulum
Scl = Sculptor
Sco = Scorpius (the Scorpion)
Sct = Scutum
Ser = Serpens
Sex = Sextans
Sga = Sagitta
Sgr = Sagittarius (the Archer)
Tau = Taurus (the Bull)
Tel = Telescopium
TrA = Triangulum Australe
Tri = Triangulum
Tuc = Tucana
UMa = Ursa Major (Great Bear)
UMi = Ursa Minor (Little Bear)
Vel = Vela
Vir = Virgo (the Virgin)
Vol = Volans
Vul = Vulpecula

The constellations with English translation are those which will best repay the beginner to know.

The twenty brightest stars in the sky lie in the following order of brightness, the first one being sixteen times brighter than the last one :—(1) Sirius (*α Canis Majoris*) ; (2) Canopus (*α Carinæ*) ; (3) *α Centauri* ; (4) Vega (*α Lyræ*) ; (5) Capella (*α Aurigæ*) ; (6) Arcturus (*α Boötis*) ; (7) Rigel (*β Orionis*) ; (8) Procyon (*α Canis Minoris*) ; (9) Achernar (*α Eridani*) ; (10) *β Centauri* ; (11) Altair (*α Aquilæ*) ; (12) *Betelgeuse* (*α Orionis*) ; (13) *α Crucis* ; (14) Aldebaran (*α Tauri*) ; (15) Pollux (*β Geminorum*) ; (16) Spica (*α Virginis*) ; (17) Antares (*α Scorpii*) ; (18) Fomalhaut (*α Piscis Australis*) ; (19) *α Cygni* ; (20) Regulus (*α Leonis*).

CHAPTER II

THE GLORY OF SEPTEMBER STARS

I

In our latitudes the star-gazer's year commences with the fall of the leaf, partly because in summer few hours remain after the long evenings of twilight when stars can be seen, and partly because after that time all of our favourite constellations begin to appear at eventide.

Some enthusiasts make a practice of beginning their astronomical year by staying out of doors from sunset to sunrise during the whole of one clear night, when there is no moonlight, in September. They can then witness the night's procession of nearly all the stars, marching from left to right while they face the south. Throughout this "march past" the stars retain their formations and relative positions, as if they were fixed to a vault of heaven which turns round an imaginary line drawn from the observer to the north star, Polaris.

During this night-watch nearly every star and constellation that ever shines in our sky is passed in review. Only those in that part of the heavens occupied by the sun, near Virgo, the Virgin, in September, are outshone by the sun at sunrise and sunset. So that on this "New Year's Eve" of the star-lover nearly every old friend comes in turn to the saluting point and claims recognition.

Even those people who have not previously learned to call the stars by their names often find that this "all-night sitting" in September serves a purpose. It introduces them to that more intimate acquaintance with individual stars and constellations which gives always thereafter a new zest to their outlook on the heavens.

On a September evening the sight of Capella, at the head of the constellation Auriga, the Charioteer, over the north-eastern horizon, warns the old hand to look out, in the next few hours, for the rising in the east of Taurus, the Bull; Orion, the Hunter; Gemini, the Twins, and all those brilliant stars which will, before the dawn, culminate in the most gorgeous star-picture that can ever be seen in the sky from any part of the earth's surface.

Such a continuous study of the star-procession, from sunset to sunrise, at one or two dates in the year, helps to unite, into one whole, the various aspects of the sky as seen in the varying seasons and hours.

On any other night it is a good plan to spend a short time, always at the same hour, every clear evening, in the enjoyment of recognizing old friends among the stars and looking out for any new features. Besides the noting of the phases and place of the moon, this practice leads to watching the movements of planets among the stars. It may lead to the unexpected enjoyment of an exceptionally brilliant meteor-shower of superlative grandeur, as was my own good fortune in 1873, on the 23rd of November, when the lost comet of Biela reappeared as the finest meteor-shower I ever saw, always excepting the unique display of Leonids on the 13th November 1866.

The same habit may disclose to view on some night an unrecorded comet. But, best of all, the habit may lead anyone to the first discovery of a new star. This luck must fall upon someone. In 1892 it was the luck of an Edinburgh man, Dr Anderson, who had the habit of interviewing the stars at 3 A.M. every night. And again, in 1902, in the same way, he was the first discoverer of a new star in Perseus, the brightest ever seen for about three hundred years. These wonderful new stars are rare. They rise to full brightness from invisibility in less than a day, and seldom remain visible to the naked eye for more than a month or two.

By choosing always the same hour for this interview with the stars, the order of procession from month to month, the same as from hour to hour, can be fixed in the mind. If a star-atlas (like Proctor's pocket one) and a flashlight be always used, anyone will be able, in a year or two, to name every star that he can see, some three or four thousand in all. The beginner may also procure a planisphere for a few shillings, to show on a circular card what constellations can be seen at any hour in any month. Later he will be able to do this in his head.

II

Suppose, then, that on a moonless September night, say between 7 and 8 P.M., one begins an all-night study of the brighter stars in

the south that follow each other from left to right throughout the dark hours. Which are the brightest stars to be seen at that hour? There are three, in different parts of the sky, that will catch the eye as being quite the most resplendent—one in the west, one overhead, and one to the east of north.

Nearly overhead is Vega, or Alpha of the Lyre constellation, shining with a soft steel-blue colour. Then in the west, above the still sunset-flushed part of the horizon, Arcturus flashes in a solitary grandeur with an orange tint. Lastly, a little east of true north, just as high above the horizon as Arcturus was seen in the west, the brilliant Capella shines yellow. Capella is at the head of a C-shaped string of stars, not all risen yet, forming the constellation Auriga, the Charioteer.

Besides these three first-magnitude stars, Vega, Arcturus, and Capella, there are many others to claim special attention at this hour, 8 P.M. in September. Half-way down from Vega to the southern horizon the bright Altair is recognized by his having two less bright companions, all in one straight line pointing up to Vega. Altair is the brightest star in the constellation Aquila, the Eagle.

Looking up again at Vega, the five brightest stars in its neighbourhood take the form of a long Roman cross, and make up the constellation Cygnus, the Swan. If the night be really clear, the Milky Way in this region will be seen to be divided into two luminous branches that meet at the Swan constellation.

Altair in the Eagle being now half-way from the Zenith to the south horizon, a glance to the left of it reveals a great square with four bright stars at the four corners. This constellation is the great square of Pegasus, and its two upright sides point to the Pole-star.

From the top left-hand corner of this very conspicuous square a string of three bright stars run to the left, being part of the constellation Andromeda (Fig. 3).

If the observer now examines the northern sky, other groups of stars, or constellations, are noted. At this hour, 8 P.M. in September, the seven stars known in this country as the Plough are very low down a little west of the north. It is part of the constellation Ursa Major, the Great Bear. It is a guide to other stars. Four of the seven stars form the ploughshare. The other three are the curved shaft of the plough or the tail of the bear.

It is a useful hint for beginners to remember that the natural advance of the plough, towards Capella, shows the direction in which all the stars are rotating round the Pole-star (see Fig. 2).

The two end stars of the ploughshare are called the pointers, because they point to the Pole-star, fairly high up in the north. A line from the middle of the plough through this Pole-star leads to the constellation Cassiopeia, or Cassiopeia's Chair. At this hour it

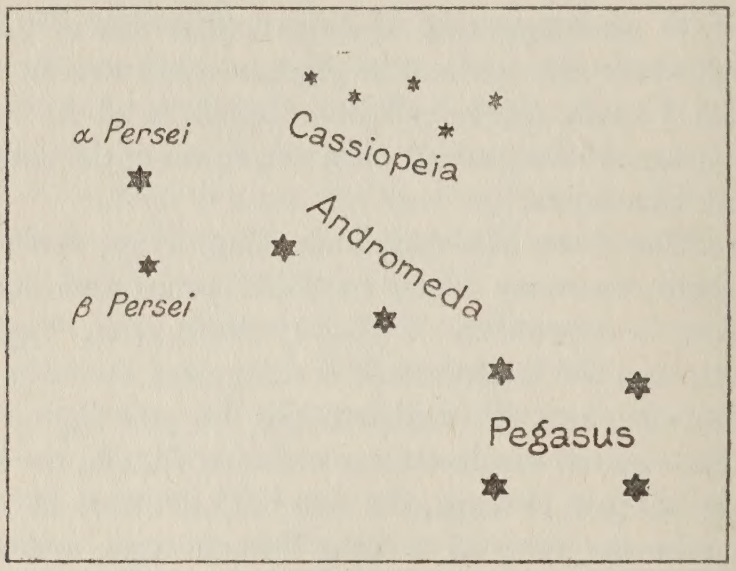

FIG. 3.—The Square of Pegasus, Andromeda, and α Persei. β Persei is Algol, the wonderful variable Star. Due south at midnight in September

is right above Capella, already identified. The five stars of this constellation, if joined by imaginary lines, would form a W written in the sky, so Cassiopeia cannot be mistaken.

Return now to the Great Bear. If you carry the eye along the curve of its tail, and beyond, it comes to Arcturus, already noted as setting in the west. This is a useful way for identifying Arcturus at any time. The same curved line carried on an equal distance beyond Arcturus would lead to Spica, the brightest star in Virgo, the Virgin. At this hour, however, Spica is below the horizon. In fact, during September, the sun is close to Spica, and prevents it from being seen (Fig. 4).

When to the glory of the few stars that have now been named is added the general impression of the less conspicuous ones, we have before us now, at 8 P.M. in September, a truly wonderful panorama.

But it is as nothing when compared with the glory that is about to arise out of the eastern horizon in the next few hours, heralded by Capella and the C-shaped Auriga.

The same panorama which we see at 8 P.M. in September, with the same stars in the same positions as now over the landscape, will be seen one month later and two hours earlier, or two months

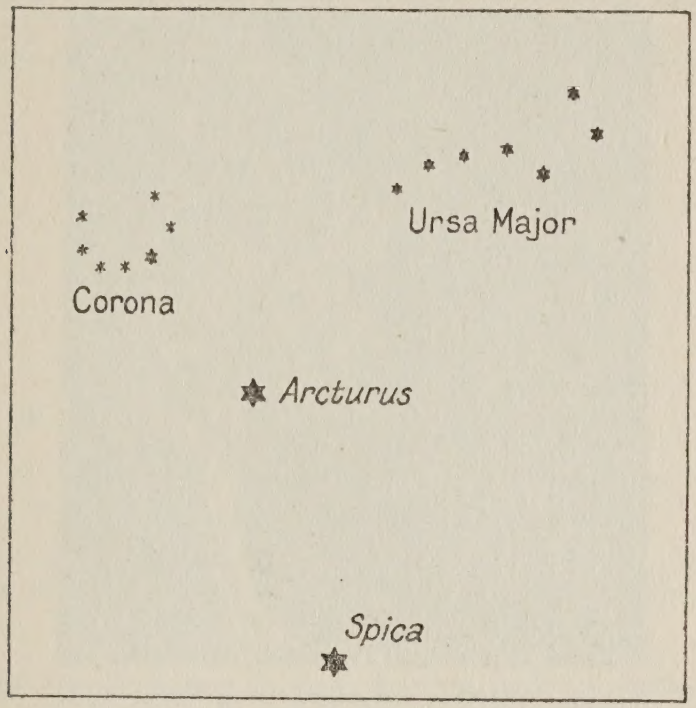

FIG. 4.—The curve of the Bear's Tail if prolonged passes through Arcturus and Spica. Due south at midnight in April

later and four hours earlier—that is to say, at 6 P.M. in October, or at 4 P.M. in November.

So also exactly the same panorama would have been seen, in the same positions as now over the landscape, one month earlier and two hours later, or two months earlier and four hours later—that is to say, at 10 P.M. in August, or at midnight in July. It is always a change of two hours for each month.

III

Having now surveyed the constellations at 8 P.M., we note that a great change occurs in the next four hours. By 10 P.M. in September Arcturus has set in the west, and Vega has climbed down from her

great altitude. But it is to Capella, the third of our brightest stars, and to her neighbours now risen or about to rise above the horizon, that the gaze of any watcher must be directed from now onwards (Fig. 5).

At 10 P.M. Capella is twice as high above the horizon. And now she shows herself as the queen of a string of five stars, shaped like a

FIG. 5.—Capella in Auriga, rising in the N.E. on a September evening, heralding the greatest glory among the Stars

capital **C**, which at this hour lies nearly on its back. All these five stars belong to the constellation Auriga, the Charioteer, except the bottom one, which happens to belong to the neighbouring constellation, Taurus, the Bull, now coming into view as the herald of the more splendid Orion. The king of the constellation Taurus is a ruddy star, just risen, and its name is Aldebaran. It is of the first magnitude. Above Capella, at this auspicious hour, is the **W**-shaped Cassiopeia.

After another two hours—that is to say, by midnight in September—the grandest constellation of all, Orion, the Hunter, is coming into view below Aldebaran. At this hour Orion has not yet assumed an upright position as the bold hunter, but is fixed in an inclined position, leaning to our left.

Hour after hour the star-gazer will watch the gradual marching of Orion to the right, and his gradual assumption of a more and more upright position owing to his turning with all the constellations round the Pole-star high up in the north, behind us.

In September the watch on Orion will have to be prolonged to sunrise before this splendid group of stars reaches an erect attitude

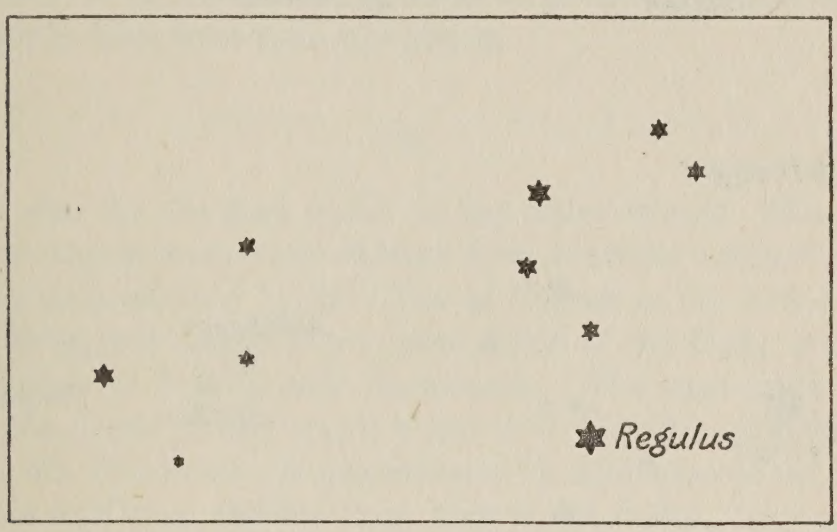

FIG. 6.—The Lion, whose head resembles a reaper's sickle. Due south at midnight in February

in the south. By that time Capella has reached a position overhead, far above the head of Orion.

During these early morning hours of the September night a succession of superb stars have risen in the east and mounted higher. First come Castor and Pollux, the golden pair of Twins; then Procyon, followed by Sirius, the Dog-star, the greatest star of all. Half-an-hour later, at 3 A.M. in September, Leo, the Lion, rises in the east. It is unmistakable, because a line drawn through six prominent stars in Leo takes the form of a reaper's sickle, with the very bright star Regulus at the end of the handle (Fig. 6).

And finally, towards the hour of sunrise in September, Orion stands erect. Two bright stars mark his shoulders; two more his legs. Three little stars indicate the head. But the three stars, in a line nearly horizontal, that mark his belt, with others suggesting a sword hanging therefrom, is the feature that identifies him best. The more so because these three stars point down to the left

towards the superb Sirius, and upwards on the right towards the ruddy Aldebaran.

Sirius and Aldebaran are the feet of an arch of magnificent stars that frame the picture of Orion. This jewelled arch includes Sirius,

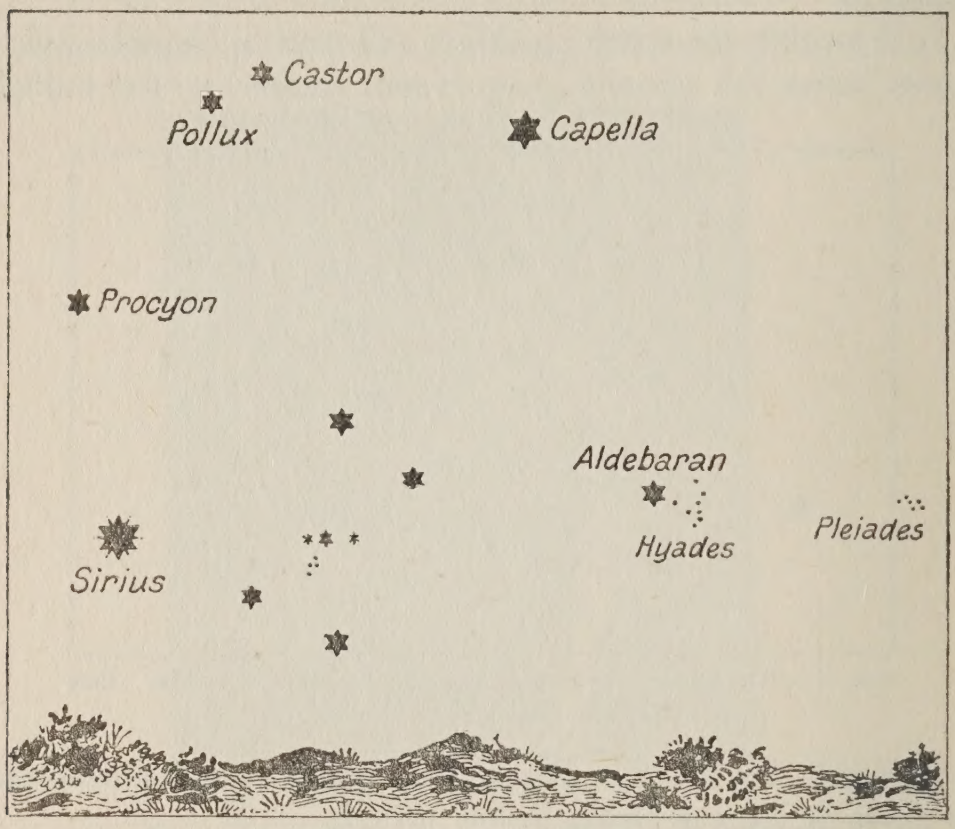

FIG. 7.—The most pleasing orientation for viewing the most glorious picture of Stars in any part of the heavens. Orion in centre surrounded by Sirius, Procyon, Pollux and Castor, Capella, Aldebaran, with Hyades and Pleiades to the right; as at 9 P.M. in March.

Procyon, Castor, Pollux and Aldebaran, some of the most beautiful of all stars (Fig. 7).

This picture is even more impressive, from the symmetry of the attendant arched frame of stars, three or four hours after Orion was in the south, say at 9 P.M. in March.

The splendour of the six stars is overwhelming, and no star in the heavens can rival Sirius, a star upon whose magnificence every human eye must be riveted in silent admiration. Yet, however much the jewelled frame may enhance the picture of Orion, it is the seven principal stars of that constellation itself with their immediate attendants, due south of us, that fascinate the beholder

at midnight of Christmas time, towards sunrise in September, or soon after sunset in March. This wonderful spectacle, with the encircling frame of such giants as Aldebaran, Capella, Castor, Pollux, Procyon and Sirius, creates a picture so complete, so exquisite, that no single one among them, not even Sirius, can for the moment claim more honour than as being a unit in this most superb illumination, a prospect which has drawn forth the admiration of all nations for a hundred generations, nay, for as long as men have been upon our planet.

IV

And now the ten-hour watch in September is over. We have noted the key-stars and constellations from Arcturus which set soon after the sun, followed by the Cross of Cygnus at the fork of the Milky Way, and Vega. Then came Altair of the Eagle, and the great Square of Pegasus with Andromeda. The stars which rose during the period of our watch began with Capella's constellation Auriga, the Charioteer. It was followed by Aldebaran of the Bull, and later by Orion, and the twins Castor and Pollux, by Procyon and Sirius, and finally by Leo, the Lion. Thereafter, Virgo, the Virgin, was due to rise, but, that region being now occupied by the sun, sunrise closed the diorama near the bright star Spica of the Virgin, and we have been able to pass in review nearly all stars from Virgo to Virgo.

Armed with an *Easy Guide to the Constellations*, a star-atlas or a planisphere, and a flashlight, this ten-hour tour of the heavens may be undertaken without further guidance. The same accessories, if used for half-an-hour at a fixed time on every clear night, will give a steadily increasing pleasure to anyone who wants to know the names of the stars and the order of their succession in the nightly review.

Having thus acquired a bowing acquaintance with the monarchs of the firmament, many a watcher will seek a more intimate friendship. Old-fashioned geography, dealing with the towns of the world, was content to indicate their position. The new geography expects its students to know about the manufactures and commerce of each town, its architecture, museums, art collections, and so

forth. So it is with astronomy. In old days people were content to know the position of each star. Now we want to know in which direction it is moving, and what it is made of. Whether it is constant in brightness, or variable, and whether it is single or attracted by a companion, revolving in a definite orbit. Is it associated with other stars of any well-determined stream ? What affinities does it possess in common with any other groups of stars. If our colour-sense be good, we notice that Vega is bluish, the Orion stars greenish, Capella yellow, Arcturus orange, Betelgeuse and Antares of the Scorpion red. In the new astronomy we want to classify all the stars in this way, and to know the meaning of these tints of colour.

It is evident that anyone who has learnt the names and places of the principal stars is sure to go on and learn what has already been done by astronomers to know the character of each star, like Vega for instance. Why does Betelgeuse, at Orion's right shoulder, differ in colour from Rigel and the other stars in Orion ? Are Castor and Pollux really so twin-like as they seem ? Or, in what points do they differ ? Is there any kind of physical connection between the individual stars that seem to be associated in one constellation, like the seven big stars of the Plough ? Which stars are nearest to us, and which of the bright ones are most distant ?

The answers to many of these questions, so far as they are known, are often hidden away in the periodical literature of astronomy. Occasionally a historian of our science, Miss Agnes Clerke, for example, has delighted us with a summary, or connected story, of these discoveries. But it is soon out of date, and the earnest student has the great happiness of being himself the discoverer of all these discoveries, in the periodical astronomical literature available in some library.

Either in that way, or else by the help of a friend who has made himself acquainted with recent astronomical observations and discoveries, the star-gazer can realize a new form of enjoyment by a more personal contact with the different stars.

The present writer, immediately on recognizing any particular star, has his memory alive with most delightful ideas that are associated with the star. This outlook is probably shared by all astronomers, each one furnished with his own series of associations,

and it is part of the great uplifting emotion that is always to them the accompaniment of a clear, starry night.

V

To explain what is meant, let us take any simple case—some bright star. Let us praise, for example, the glory of Arcturus, because after this month of September it will have ceased to shine upon us, being then approached too closely by the sun.

It so happens that I never see Arcturus without recalling the fact that this was one of the first three stars whose places were found by Halley, two centuries ago, to be sensibly changed since the time when they were recorded by the ancient Greeks, or even since Tycho Brahe.

Halley, one of our great Astronomers Royal, found that, since the days of Hipparchus, Arcturus has moved among the other stars through a distance actually amounting to two and a half times the apparent diameter of the moon.

And since, more recently, the distance of this star from us has been measured, we now know that this means that the motion of Arcturus, at right angles to our line of sight, is at the prodigious rate of two hundred and eighty-eight miles every second, and that it is now eighteen million million miles away from the position in which it was marked by Hipparchus.

The thoughts then wander to the proper-motions of other stars, to the ingenious device now being used by Eddington and by the Astronomer Royal, at Cambridge and Greenwich observatories, for superposing star-negatives photographed at two dates twenty or thirty years apart. In this way even minute motions of the stars are being detected and measured. Then the thoughts about Arcturus carry us in admiration to the great American catalogue of the proper motions of twelve thousand stars. And we then recall how Eddington, by the use of this catalogue, was able to confirm Kapteyn's marvellous discovery of systematic motions among the stars.

Twenty years ago Kapteyn, of Holland, made a most surprising discovery—that most of the stars belong to one or other of two great star-streams that are travelling in opposite directions.

There are many other smaller swarms of stars, each swarm having its own velocity and its own direction of motion. But Kapteyn's two opposing star-streams are the greatest wonder of all.

So much for the glory of Arcturus and proper-motions. A similar kind of association of ideas is aroused by the glory of Vega, Capella, Sirius, the Great Bear, or the Pleiades. Each has a totally different story to tell, always full of interest.

So it may well happen that many a beginner who spends a whole September night with the stars goes on to recognize individual peculiarities. Then, passing from guide-books and atlases, he may himself become an explorer among the orbs of heaven with the help of a telescope. Once started in this way, there are few who would not seek, by books and companionship, to become real students of the most sublime of all the sciences. Some of these enthusiasts, if perseverance upheld them, might add to the discoveries which rejoice the hearts of all real astronomers.

So the all-night sitting in September has led us on to great thoughts about the heavenly hosts. It has also exposed to us, hour by hour, the changing aspects of the night sky that we shall behold in the evenings from month to month during the winter.

CHAPTER III

HOW TO KNOW THE PLANETS

I

EVERYONE who has seen Turner's picture of the Dogana, Venice, or even the fine engraving of it, must have felt that it owes not a little of its charm to the bright evening star shining in the glow of sunset. Many an artist besides Turner has known how to catch, on a still evening, the soft beauty of Venus beneath the thin crescent of the young moon, as a part of his sunset-picture, say, of the warships in Portsmouth harbour. Or, at that hour, he has been able to add something to the pink antiglow of sunset in the east, by choosing an evening when Jupiter and the full moon are reflecting their beams on the harbour's ripples.

Jupiter, Venus and the other planets (that is, wanderers) differ from the rest of the stars in two respects. They are not fixed, but move about from one constellation of stars to another. And again, each of them varies in brightness from month to month, and it is only now and then that any one of them actually compels our attention, unless we are very careful watchers of the stars.

It may surprise some of the less careful watchers to know that there are only five of these planets ever visible to the naked eye. All of them are occasionally very bright. They are Mercury, Venus, Mars, Jupiter and Saturn. And for practical purposes Mercury may be left out of account, because he is small and, being never more than twenty-three degrees away from the sun, he is seldom seen in our climate.

The four principal planets, brilliant lamps of the sky, are admired by all, and often we hear the query : "What is that lovely star we see every evening now in the west ?" The answer is very sure to be : "The planet Venus"—a round planet that shows in a telescope all the phases of the moon, but in a year and a half instead of one month.

Sometimes the query may take this form : "Before going to bed, lately, we have been noticing a wonderful great star in the south. What star is it ?" The answer will be : "It must be a planet—either Mars, Jupiter or Saturn." An astronomer might,

of course, know which of them is in that direction at that time. But a moment's inspection would suffice to make this known to anyone who cares enough about the stars to notice things for himself.

It is certainly a pleasure to know some of the fixed stars by name ; but they are always in the same place among the others, and of the same brightness, except in hazy weather. It is a much greater pleasure to find a planet in its wanderings, and to be able to welcome Mars or Jupiter by name after many months of absence.

Everybody knows about the solar system—that you can make a rough representation of it on a flat plane table by putting a ball in the middle of the table for the sun, and drawing circles on the table for the orbits of the planets. These would be represented by little balls moving on the circles all in one direction (anti-clockwise, if we suppose ourselves to be looking at the table from the northern hemisphere). And the planets in the smaller circles move quicker than those in the larger circles. Of course it is also well known that the orbits of different planets are not exactly circles, but ovals, and they are very slightly tilted to the table, on whose surface our earth is supposed to move. But the tilt is found to be very small, and need not be considered at first (Figs. 8 and 9).

Now it is all very well to say that everybody knows this because he has read it in a book, but it is far better if we can find it out for ourselves. Then we shall be able to distinguish the planets from other stars and from each other, and this is what the books do not generally tell us.

II

There are three ways of knowing a planet as such when we see it. The first two are very quick and easy to apply, but not so certain as the third. The first clue is this : Whenever you see an unusually bright star, unless it be Sirius, it is probably a planet, in that part of its orbit where it becomes brightest to the inhabitants of our planet the Earth. Take Venus, for instance, on a circle that is always inside the earth's orbit. She does not shine by her own light. The half of her next the sun is lighted by the sun ; the rest of her is dark to us. So, when Venus is nearest to us, we are looking at her dark side, which is invisible. When she moves a little away from there we

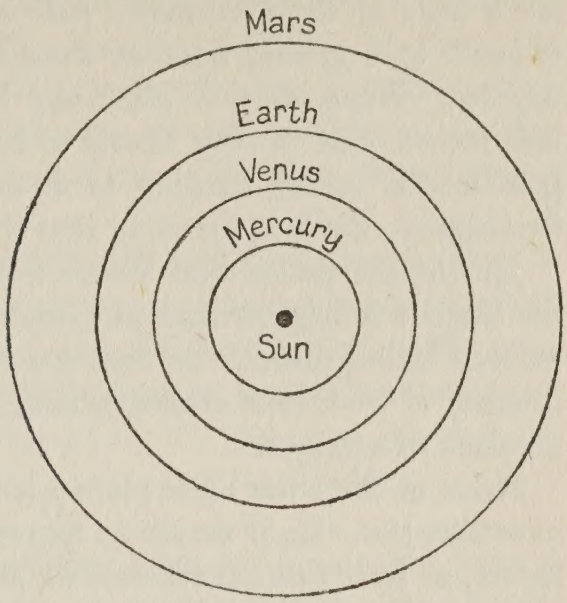

FIG. 8.—The orbits of Smaller Planets. Distances from the Sun are 4, 7, 10, 15; the Earth being 10

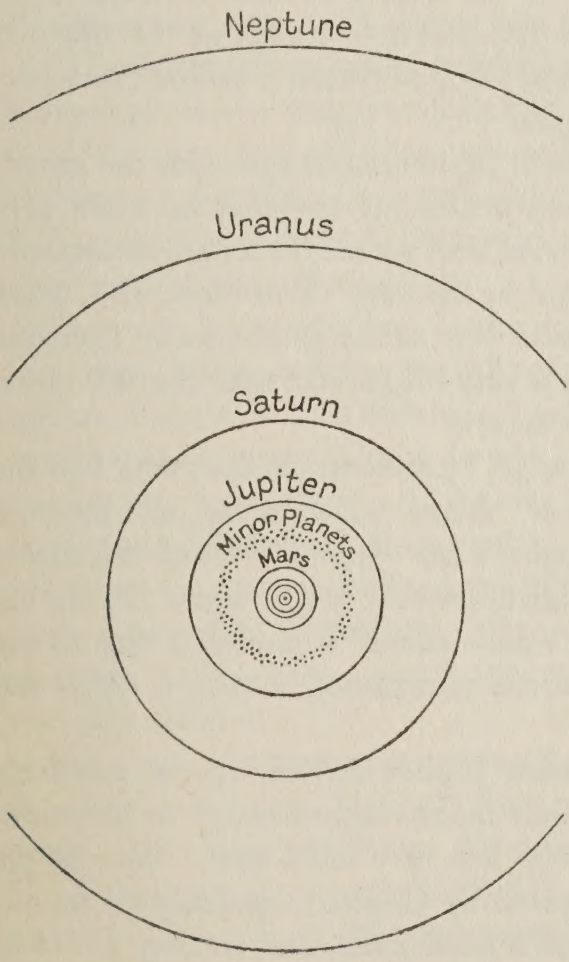

FIG. 9.—The orbits of Greater Planets. Distances from the Sun are 52, 95, 192, 301; the Earth being 10

see a little of the illuminated half like a crescent moon. Venus is never at a greater distance from the sun than about forty-five degrees. When at that place she looks in the telescope like a half moon. She is then nearly at her brightest. For when she goes farther round, turning to us the whole of the illuminated hemisphere, she is so far away that the light is much feebler.

During the period that Venus is about forty-five degrees from the sun she is brighter than any other star or planet, and can easily be seen before sunset. In fact, she can then be seen sometimes at midday, if you know where to look ; and she casts a shadow on the deck of a steamer.

None of the other three planets is brightest when near the rising or setting sun. So, if we see an extremely bright star in the west at sunset, or in the east at sunrise, we are very safe in asserting that it is Venus. The crescent moon also is never far from the sun. This is the reason why a very brilliant star near a delicate crescent moon is probably Venus. But the full moon is always at the opposite part of the sky to the sun. And for that reason a brilliant star near the full moon cannot be Venus.

As to the other planets (Mars, Jupiter, Saturn) outside the earth's orbit, they are brightest when nearest to us—that is, when sun, earth and planet are nearly in line, and we see the whole hemisphere of the planet that is illuminated by the sun. The moon also, when at the full, is nearly in the same line as the planet, away from the sun. That is the reason why a very bright star near the full moon is probably Mars, Jupiter or Saturn.

It is generally possible to judge, by mere inspection, which of the three planets we are looking at. Mars is always red, and becomes fiery red when it is nearest to the earth. Jupiter is much the largest of all the planets, and is invariably a very bright star ; but he has not the red colour of Mars, which colour is doubtless due to the sandy soil of Mars. The more distant planet, Saturn, is duller and yellowish.

With a pair of opera-glasses Jupiter can always be positively recognized, because he has four moons large enough to be almost visible to the naked eye, besides five very small ones. Some of the four Galilean moons (discovered by Galileo)—possibly all four—may be seen at any time with a small glass, and, as they are close

to Jupiter and all lie on a line going through the planet, they cannot be mistaken, though constantly changing position. If, then, the glass shows three or four small specks of light on a line going through the planet, we may be sure we are looking at Jupiter. These moons changing their positions on the line are a constant delight.

If you direct upon the planet Saturn a telescope larger than the little one that shows Jupiter's moons, you know at a glance which planet it is. For it is not round, but elongated, owing to the marvellous flat ring that surrounds its equator, generally tilted at an angle.

III

The second clue for identifying a planet among the stars is most useful when the planet is not at its brightest—not brighter than some of the fixed stars. *The fixed stars generally twinkle, the planets almost never.* Everyone has noticed on a clear night the rapid flashing of stars, called twinkling or scintillation. It is caused by small patches of irregular density in the atmosphere which deflect from the eye a ray of light that ought to reach it. The effect is momentary, because the patches are in motion, and quite small. It is constantly repeated, because there are many patches. Some stars twinkle more than others.

Everyone knows that our atmosphere bends a ray of light from a star downwards, and that the light of a star contains rays of different colours that are bent to different degrees by the atmosphere. Thus the rays of different colours do not follow exactly the same paths from a star to our eye. It follows that the atmospheric patches causing scintillation, in their motion, deflect the different colours not all at once but in succession. This is easily seen in a spectroscope attached to a telescope. But a very pretty experiment may be made without any special apparatus, showing the effect in a beautiful manner.

If a small telescope or an opera-glass be pointed to a star, and if we keep on tapping the instrument, then the star seems to move about. Its image persists on the retina for a fraction of a second. So the moving star-image looks like a string of light that can be twisted into a coil of different shapes by judicious tapping.

Now, if the star be a good twinkler, the string of light seems to have gaps in it, showing when a patch is deflecting the ray of light out of our line of vision. But this is not all. The patch deflects different colours in succession. Sometimes green, sometimes red, is deflected from the eye. The result is that the string or coil of light is converted into a beautiful pearl necklace, interrupted, not by mere dark gaps, but by the brilliant scintillations from diamonds, rubies, sapphires and emeralds. Try this experiment, and show it to your friends.

These remarks on twinkling help to explain why fixed stars twinkle and planets do not. A star is at such an enormous distance that, in spite of its great size, it looks like a mere point of light. But a planet is near enough to show a disc of sensible size in a telescope. A patch in the atmosphere may deflect from our line of sight a ray of light coming from a point, and yet be too small to affect all the rays coming from different parts of the planet's surface. This is the reason why you may be sure that a star which twinkles is not a planet.

IV

The two clues already given for distinguishing planets from other stars are not absolute. The third clue is the only sure and certain test. It depends upon the position of the doubtful object among the other stars.

After we have got to know some of the constellations, and noted the places occupied by planets, we make this great discovery : that planets do not turn up in all parts of the heavens. In the greater number of the constellations planets are never seen. There is, in fact, only one straight road or track among the stars, and not a very broad one, in which we ever see a planet, or the moon or the sun. At first it seems almost absurd to speak of the sun following a track among the stars, as we do not see the stars in daytime. But this happens only because the sun's light illuminates the atmosphere and makes it brighter than the stars. It is a surprising truth that the stars are shining just as brightly by day as by night. The sun and the moon, being both wanderers among the stars, were in old days included among the planets.

How can we find the path among the stars followed by the sun,

the moon and the planets? Sometimes we have the good fortune to see three planets at the same time. In that case we can see for ourselves that the path is a straight line right round the earth. It is not easy to imagine correctly a straight line among the stars. The best plan is to hold up a walking-stick, and we find that it covers all three planets at the same time, provided no two are very close together. This is true all through the year, so the track is continuous right round the earth. Thus we learn from our own observation that the planetary orbits all lie nearly in one plane, like the flat table spoken of above.

While holding the stick in line with any two planets it is easy to note those stars and constellations that are covered by the stick, and to continue the line among the stars that form the apparent path of the sun, the moon and the planets. This path is called the ecliptic: a word strictly used for the path of the sun among the stars, but applicable also as a rough guide to the paths of the planets and the moon.

In this way we might be fortunate enough to see the moon half-way between Aldebaran and the Pleiades, while Mars might be in the Twins, farther from the Pole-star than the bright stars Castor and Pollux. If Saturn happened at the same time to be near the bright star Regulus in the Lion, and Jupiter at Spica in the Virgin, we should be able very easily to trace out with our stick the whole of the northern half of the ecliptic, which, to us in these latitudes, is its most interesting part.

With the help of a star-atlas, or some *Easy Guide* containing pictures of the constellations, it is a very simple affair to get to know the constellations lying upon the ecliptic, the twelve signs of the zodiac, which divide the yearly path of the sun into twelve months. This occupation goes far towards completing our familiarity with any stars that happen to be shining, at any time of the year.

After this has been done no one can be in doubt about a planet. If a star we are looking at is not on the ecliptic it cannot be a planet, and, knowing all the bright stars on the ecliptic, we cannot mistake them for planets.

V

Every astronomer can remember the time when he first reached this stage and acquired the habit of watching the movements of the planets along the ecliptic. It is a good plan to draw a picture of the stars among which Mars or Jupiter is moving, and to mark the planet's place from week to week. Saturn takes thirty years to complete the circuit. Jupiter passes into a new sign of the zodiac each year, taking twelve years to go right round. Mars takes about two years.

All the planets revolve in their orbits from west to east—that is to say, from *right to left*, as we look at them in the southern half of the sky. But strange as it seems, our star-picture on which we mark, from week to week, the place of Mars, Jupiter or Saturn at its brightest—that is to say, " in opposition " to the sun—shows it to be apparently moving for some months in a retrograde path, from *left to right*. It was the understanding of this retrograde motion that led Pythagoras and Copernicus to insist that our earth is a planet revolving round the sun between Venus and Mars. They recognized the retrograde motion as being an optical illusion, such as we ourselves are accustomed to see when two railway trains or two ships are moving side by side and we are in one of them. The motion may be so smooth that we do not take account of it. The other ship seems to move in the true direction of motion only when it is going faster than we are. If our ship is the faster, the other seems to lag behind or to be moving with retrograde motion when we compare its place with the distant shore.

So it is with Mars, Jupiter or Saturn. At a time of " opposition " the earth and the planet are moving on parallel courses, and the earth moves quicker than any of them ; so the planet seems to move backwards among the stars, until the earth in its circular orbit has changed its direction, and no longer gives us the optical illusion of retrograde motion. Of all the planets showing retrograde motion Mars is the most remarkable. It is so much nearer to us than Jupiter or Saturn that the extent to which it seems to double on its track and go backwards makes it appear to be the most flighty and erratic of them all.

These hints and clues that have been thrown out to help anyone

[*Photographed at Lowell Observatory, U.S.A.*

PLATE I.—SATURN'S RINGS

[*To face page* 43

to know the planets have often led people to take a new interest in the firmament. Then with the help of books and a telescope they have rejoiced in a new hobby. Others, fortunately for us all, have gone further and have therein found a new and permanent aim in life. It is thus that many an astronomer has made himself, and has trained his eye, hand and intellect to work as the servants of the human race, by revealing to us the wonders of the heavens, and the immutability of the Creator's will in the enforcement of those laws which He has established for the working of a world and the evolution of a universe.

VI

It is not possible here to describe the planetary wonders that are disclosed by the telescope, but we may give a brief glance at the telescopic wonders that exist on two of the planets.

Pointing a good telescope at Saturn, the most distant planet visible to the naked eye, we have a vision of so startling a character that no other sight known to astronomers could have suggested the possibility of such a structure. We on this earth are glad to have our single moon to guide our way on a dark night. Saturn rejoices in nine and perhaps ten moons. But the really marvellous feature of Saturn, stranger than any other heavenly object, is the great bright flat ring surrounding its equator, generally tilted at an angle to us. Twice in each revolution of Saturn—that is, every fifteen years—when we see Saturn in the constellation Leo or Aquarius, this ring is edge-on to us ; and it is so thin (only fifty miles thick) that at these times the ring is invisible in a telescope. It was like that in the year 1821. That fifty miles, at the distance of Saturn, is like the thickness of a sheet of paper at three miles, and cannot be seen. Tilt it, and the reflected light from the paper or from Saturn's ring is brilliant. Large telescopes show this marvellous flat ring to be divided into concentric circular flat rings, separated by black empty space. The innermost ring is darker and semi-transparent (Plate I.).

If Saturn is a marvellous object as seen from the earth, our imagination is bankrupt in attempting to think of the midnight splendour as seen on that distant world. It has nine moons, mostly

on the line of the ecliptic, many of them above the horizon at the same time, some full moons, some at the quarter or crescent, and they differ greatly in size. Winter on that planet must be appalling, as it lasts for seven years instead of three months, and all that time the ring acts as a screen, shutting out the sun's rays by day from nearly half the planet. But who can truthfully describe the aspect of the great flat equatorial ring, illuminated on the one side by the sun during the nights of a Saturnian summer ?

For during the summer of the northern hemisphere the great arch of light is shining as if with the light of a thousand moons upon land and sea, with an inner arch of clear sky and stars low down on the southern horizon. The bright surface is divided by thin black rings that separate the concentric bright rings. And at this season, at midnight, the sun casts a shadow of the planet on the ring, and a great upright arch of the ring is cut out from the sun's light, leaving it black. Thus at midnight the central southern parts of the ring are in darkness, though tinged at their edge by the colours refracted through the planet's atmosphere. This leaves only two horns of white light, with a rainbow-coloured sunset on their inner edge, rising from broad bases in the south-east and the south-west, both curving southwards and towering upwards, to meet in a thin bright connecting-line at the top. This wonderful pair of luminous horns of the ring rise in the east, and set in the west every night. The height to which the brilliant arch of light attains in the sky depends on the latitude. In the Arctic regions the ring is wholly invisible, and from places nearer to the Equator the stars could be seen under the central arch, which is there nearly overhead. Certainly a telescopic examination of Saturn opens the gates of speculation and conjecture to an extent that ought to satisfy the most imaginative of poets.

VII

To pass from the most distant of the three bright exterior planets to the nearest one, Mars is so much closer that it excels all other planets in distinctness of details. Its surface is marked by shades and tints, dark and bright, with definite boundaries and shapes that are permanent. These suggest the notion of continents surrounded by oceans. We see the planet rotating regularly in twenty-four

hours as the earth does. We observe its axis of rotation to be inclined like the earth's axis, giving the seasons of summer and winter on Mars, as with us. The North and South Poles are each covered with a brilliant white cap, suggestive of snow and ice, like our Arctic and Antarctic regions. Moreover, astronomers have discovered by exact measurements that after the season has passed, in northern latitudes, from winter to summer, the size of the ice-cap at the North Pole has diminished, probably from the snow melting, while that at the South Pole has increased. Signs of vegetation growing at that season and darkening the soil have been suspected. Be this as it may, enough has been certainly observed to assure us that in many respects the two planets Mars and Tellus (our earth) have much in common.

When this has been accepted, not merely as an authoritative statement, but from frequent examination with a telescope, we remain convinced that Mars is a world like ours, and that our world is a planet like Mars.

On reaching this conclusion speculation becomes inevitable, and we ask ourselves the great question : " Do men and women inhabit Mars and the other planets ? " Once started, speculation will carry us still farther. We know that the stars are suns, like our sun. We know that some at least, and possibly all, have colder bodies, or planets, revolving round them ; and we ask : " Are there solar systems among the stars ? And is each star the centre of a system of planets, as our sun is, and is each one of these planets inhabited by a race of human beings ? "

Such questions are hard to deal with. There are astronomers who have watched the annual changes on the planet Mars for years and years, who assure us that they have detected signs of human contrivance and workmanship upon Mars, in the form of gigantic canals made for irrigation.

The ruddy hue of Mars which we perceive is due to its soil. Of that there is little doubt. This seems to imply that the continents upon Mars are mostly made of sand like our deserts. If this be so, the Martians may suffer from drought, and might well be expected to tap the source of water in the melting polar ice-caps, and lead it in huge irrigation-canals to water the deserts, and to cultivate their banks and near-by lands with crops and vegetables, in the

manner of the Egyptians with their source of water supply, the Nile.

Much has been written in favour of this view by responsible astronomers ; but the disbelievers are many, both as to the accuracy of the observations and the fairness of the deductions. For the present we will leave it at that. It must, however, be remarked that on most of the planets, if not on all, the conditions of temperature are such that it is unlikely that human beings made as we are could exist.

People who delight in controversy as to whether there are human beings on the other worlds generally admit the truth that there is no scientific evidence on one side or the other. So they indulge in non-scientific speculations as to what they themselves consider the most probable, and this opinion depends often upon their notions about what the Creator's purpose was in the creation. In all this kind of discussion most astronomers patiently and in all humility await some real evidence. " Canst thou by searching find out God ? Canst thou find out the Almighty to perfection ? "

CHAPTER IV

THE PLANET MARS

I

During the month of August in 1924 many people were asking the question : "What is that fiery star low down near the southern horizon ?" It was the planet Mars, that revolves round the sun in an orbit outside of the earth's orbit, nearer to the earth than the orbits of Jupiter and Saturn. It was seen in August 1924 to rise at 9 P.M. and to set at 3 A.M. At midnight in the south it was no higher in the sky than a December sun at noon. In that year Mars made a nearer approach to the earth than it will do for a century.

The earth travels quicker than Mars in its course round the sun, and overtakes it every two years and seven weeks. At the exact time when Mars is being overtaken he must be in line with the earth and the sun. He is then nearer to the earth than at any other time. So he looks far brighter than usual, and this is why people notice the planet when it is in "opposition" to the sun. His red colour is generally attributed to the colour of his soil, like red sandstone.

It is interesting to make a little sketch of the stars near to Mars in opposition, and to mark his varying position among the stars from week to week. His general course is found to be from west to east, or from right to left in our latitudes. But, at the time of opposition, Mars and the earth are travelling in parallel courses. And the fact that the earth travels quicker and Mars lags behind makes the planet seem to be travelling backwards, from left to right, among the stars.

On 26th July 1924, in its ordinary course from right to left, it reached a notable group of small stars in the middle of the constellation Aquarius, the Water-bearer. Here, for a day or two, it remained stationary, so far as we could see. Then it flew rapidly to the right through nearly fifteen degrees, half-way across that constellation, and there became again stationary, on 24th September. Again reversing its direction, it presently acquired its steady rate of motion from right to left. On the 23rd of August it was in opposition, nearest to the earth and at its brightest. This retrograde

motion, at times of opposition, was a great puzzle to the ancient astronomers. If they looked on the earth as being fixed in space, with the sun and Mars going round it, clearly they would have to give to Mars a very funny route, sometimes going backwards (Fig. 10).

Pythagoras, however, and his school of followers, including the great Plato, seem to have pointed out what has been stated above, that the apparently retrograde motion can easily be explained if the earth goes round the sun in a circular orbit, and Mars in a larger circular orbit, more slowly than the earth.

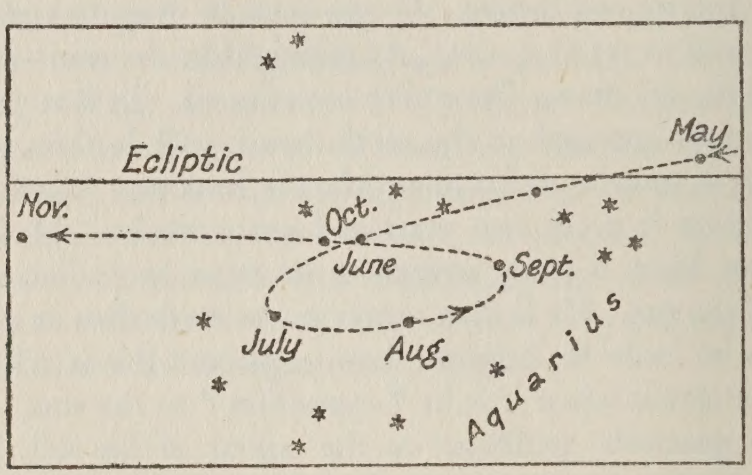

FIG. 10.—Retrograde motion of Mars from July to September during the opposition of Mars in 1924, in Aquarius

These philosophers thought that this simple circular motion was far more likely to be the true one than the queer forward and backward motion of Mars, on the theory of the earth being at rest.

But the ancients generally could not believe that the earth moved. So at last the great Greek mathematician, Apollonius, showed how two circular motions, such as were favoured by the great Plato, could, if ascribed to Mars, give the appearance of retrograde motion with the earth fixed in space. He gave to Mars a double circular motion like a waltzer in a ballroom, who describes one circle round his partner and another round the room. Anyone in the middle of the room would see the waltzer moving round the room, on the whole from right to left, but with occasional stationary points, and retrograde motions from left to right.

This theory of Apollonius was adopted by Hipparchus, Ptolemy, Aristotle and all philosophers for over sixteen centuries, until

Copernicus directed attention to the greater simplicity of the Pythagorean theory of a moving earth. Finally Kepler discovered, from the accurate observations made by Tycho Brahe on Mars during twenty years, the exact shapes of the nearly circular planetary orbits.

II

Mars is, in many ways, the most interesting of the planets. It is much nearer to us than Jupiter or Saturn, so we have a closer view of its features. Venus sometimes comes still closer to us, but at such times its illumination by the sun leaves most of it dark and only a thin crescent is visible, for Venus then lies nearly between us and the sun.

Certainly we can map out the topography of Mars better than that of any other planet. With a good telescope we can see dark and light areas, like continents and oceans. Also we can see that the Arctic and Antarctic regions are covered with ice and snow. By watching with a telescope the movements of some dark area, the rotation of Mars, like that of the earth, is established, and it is found to take about twenty-four hours, just as in the case of the earth. Moreover, the inclination of Mars' axis of rotation to the ecliptic is about the same as in the case of our earth. Since the character of our seasons depends upon that inclination, it follows that the seasons on Mars must resemble our own seasons. In fact, a telescopic examination of Mars shows a great resemblance to terrestrial conditions, except that the year is nearly twice as long, and being so much farther from the sun it gets less heat from it. Mars offers more conditions suitable for the life of human beings than any other planet. But it is doubtful if we shall ever be able to find out whether it is inhabited or not.

There was one thing that used to surprise astronomers. The Earth, Jupiter, Saturn, Uranus and Neptune all have moons or satellites. Mars showed none. Venus and Mercury might perhaps have moons that are invisible owing to the blazing light of these planets themselves.

In 1877 a splendid 26-inch refractor telescope had been set up at Washington, U.S.A. ; and when the director, Asaph Hall, turned it upon Mars during opposition he discovered two minute

moons, each a few miles only in diameter. But these moons differed from all satellites that were then known, in being so near to the surface of the planet that they take only, the one seven and a half hours, the other thirty and a quarter hours, to revolve round the planet Mars, whose daily rotation is completed in twenty-four hours.

This unique phenomenon would enable an inhabitant of Mars to see the inner moon Phobos revolving every night from west to east instead of the normal nightly rotation from east to west, sometimes showing three full-moons in one night, with all the phases, waxing and waning, completed in the intervals, exhibiting within a few hours the gibbous and crescent forms and the first and last quarters.

In connection with this discovery, mention must now be made of the most extraordinary fulfilment of a flight of human imagination that has ever been developed in the world's history.

Swift wrote the imaginary travels of Gulliver in the year 1726. He then spoke of the astronomers in the Island of Laputa as being furnished with telescopes so wonderful that they discovered not only one but two moons revolving round Mars, very close to the planet, one completing a revolution round Mars in ten hours, the other in twenty-one and a half hours.

It is surprising that he should have said there were *two* moons, which is true. But it is simply astounding that he should have attributed to them periods of revolution so small as to be utterly at variance with any facts known about the solar system. And it seems actually miraculous that he should have stated, so nearly to the truth, the periods of revolution of these two moons of Mars, which were never even seen till a century and a half later.

III

The new astronomy owes more to photography and the spectroscope than it does to any new development of instruments, great as these have been in the lives of many of us.

Photography has been of service to astronomy in three different directions : (1) delineation, (2) position, (3) discovery. It was first used for the delineation of the moon's features by Warren

de la Rue, Bond, Rutherford and others. De la Rue then applied it to the sun to delineate the solar spots and faculæ, and also the phenomena of solar eclipses and transits of Venus. The successful extension of this art to planets is more recent, and was largely due to the study of the planet Mars, as will now be told.

After photography had proved its superiority to the human eye in portraying accurately the markings upon the sun and moon, it seemed reasonable to expect a like success in the portrayal of markings upon the planets. The first attempts, however, dispelled that expectation, and the reason is very obvious to anyone who has, with a telescope, sought to make a drawing of the fainter markings on any planet such as Mars, Jupiter or Saturn.

The markings upon a planet's surface, beyond the broad outlines of continents, perhaps, or of belts of cloud, are often extremely feeble, and difficult to observe. The transparency of our atmosphere is not steady, but varies from moment to moment. So does the stillness of the air which is essential for clear definition. Any movements of the atmosphere tend to blur and confuse the feebler markings on the planet.

On looking through a telescope at Mars or Jupiter, after a long wait, a momentary flash of exceptionally clear vision may disclose the existence of a spot, or a line, or mere dots, that had up to that moment been invisible. And the observer must then mark upon his drawing these glimpses, while he goes on looking, in hopes of confirming or correcting his first impression. Thus his picture may be filled in with details which are not seen by him all at once, but only "glimpsed" occasionally.

Now, a planet differs from the sun, or even the moon, by the feebleness of its light. It requires a much longer exposure to produce a photograph, a duration of time generally much longer than the duration of any one of those exceptionally clear moments of vision. Details become obliterated by atmospheric fluctuations during the time required for exposure.

Thus it happened that disappointment was met with in all early attempts at delineation of the surface of a planet by photography. This arose from the absence in the photograph of those glimpses that can be caught visually. But everyone looked forward with hope, and we still do so, to a time when photographs of the planets

will be as clear and superior to visual drawings as are those of the moon or of nebulæ.

One of the greatest charms to many of us in the history of astronomy lies not so much in the wonderful discoveries that have been made as in the dogged perseverance, patience and skill of the astronomer in his continuous and unremitting search for truth. And the partial success that has been attained by the effort to photograph the finer details of the planet Mars is one of the best examples of this spirit.

Its history is worth recording here as a pleasing tribute to the untiring perseverance of the late Percival Lowell at the Flagstaff Observatory in Arizona, U.S.A., in his prolonged study of the planet Mars.

IV

Up to the year 1877 the features depicted in drawings of Mars were permanent markings, perfectly clear and definite. In that year, when his moons were discovered, Mars and the earth came unusually close to each other, and Schiaparelli, for the first time, detected certain straight lines forming a kind of network over parts of the planet. The straightness of these lines did not look natural, and the suggestion was made that they were artificial canals made by human beings. At a later opposition of Mars the same astronomer declared that many of the canals were double (Fig. 11).

Some people of imagination have looked upon the canals as means of transport between industrial towns situated at their points of intersection. The duplication of canals might have become necessary on account of the increasing traffic : one for the up trains, the other for the down trains, of canal-boats.

On the other hand, some have looked upon the canals as a huge artificial system of water supply for irrigation. If the red colour of Mars is due to the soil being a sandy desert, then the absence of water in these desert regions may have led to the construction of canals to bring water from the polar regions when the ice melts in summer time. For we do find that the ice-caps covering the north and south poles of Mars, as on our own planet, are seen to grow in the winter of Mars, and to be melted and shrink during its summer, alternately in the two hemispheres of the planet.

A great number of maps of the planet were drawn by those

astronomers who were fortunate enough to detect these canal-like appearances. Among these, no one was more diligent, or more successful, than the late Percival Lowell, whose acquaintance I first made at the observatory of Harvard College, over thirty years

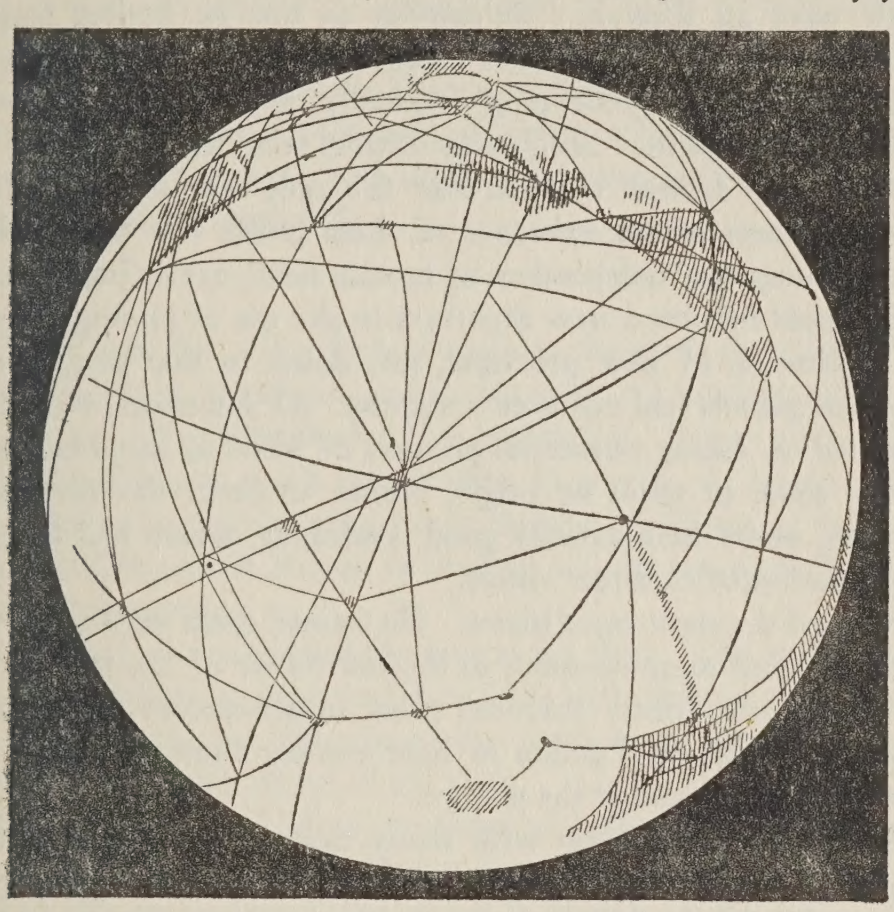

FIG. 11.—Hemisphere of Mars, one of very many drawings by Percival Lowell, showing some of the canals which he saw, or thought he saw, at the Lowell Observatory

ago. He set up a magnificent 24-inch telescope, in the clear atmosphere of the high altitudes of Arizona, at the Flagstaff—or Lowell—Observatory.

While Lowell was thus confirming the observations of Schiaparelli, many other astronomers could not see the canals even with larger telescopes than his. They doubted the reality of the network of canals, and they suggested that the pictures by Lowell and others were the result of imagination, and that he unconsciously joined any spots or marks there might be into straight lines extending over great distances. Lowell, on the other hand, attributed his

own positive results, where others failed, partly to superior qualities in his telescope and partly to the climate.

Lowell continued, at successive oppositions of the planet, to confirm his original discoveries. Still the doubters insisted that the canals were an illusion. In answer to this he invited sceptics to his observatory. Again and again these independent observers, when favoured by moments of unusually clear vision at Flagstaff, confirmed his results. Still, many sceptics were not convinced.

Thereupon Lowell realized that the only way for convincing all astronomers of the existence of these canals was to secure an actual photograph independent of human hand, eye or imagination. This would involve a new departure in the use of photography by the application of new processes, for, down to that date, photographs of planets had not been a success. All his efforts were concentrated on taking numerous pictures of Mars so instantaneously that in some of them he might chance to catch the favourable glimpses, under momentarily good conditions, which had hitherto been vouchsafed to direct vision.

He used the most rapid plates. He stained them with a dye that rendered them more sensitive to the red colour of the planet. He also interposed faintly coloured films to accentuate the contrast between the chemical action of light coming from the canals and from the background of the picture.

At every step, though with many failures, his hopes became brighter. After years of laborious trials he was able to get a clear picture with an almost instantaneous exposure. Then he proceeded to take on each plate a great number of exposures in rapid succession, on different parts of the photographic plate. Eventually he succeeded in occasionally finding really good definition in some of the images.

In this way Lowell was ultimately able to circulate among astronomers photographs which, although they did not exhibit every detail which he had glimpsed in his eye-observations, did certainly prove to the world the existence of these lines which he considered to be artificial canals.

He did not assert that the great breadth of the lines was all canal. He claimed that the lines indicated not only the canals, but also the belt of vegetation that would inevitably spring up to some

distance on each side of the banks of the canals ; as can be seen on the banks of the Nile.

Since the death of Lowell, his chief assistant and successor, Mr Slipher, has continued the good work with great perseverance. He tells us that the number of photographs of Mars already taken at the Lowell Observatory considerably exceeds one hundred thousand.

Quite recently, by the application of these new processes, he has produced marvellous photographs of Jupiter, which have been the admiration of all who have seen them. Ten years earlier such pictures would have been impossible.

V

Every time that a line from the sun to the earth overtakes Mars, that planet is in opposition, and at that time it is nearer to the earth than at any other time during that revolution. But at some oppositions the planet is much nearer than at others. It comes nearest to us when the opposition occurs in the end of August or beginning of September, and in August of the year 1924 it was only thirty-five million miles away.

It is easy to understand the reason for this. The earth's orbit, though elliptical, is very nearly a circle with the sun at its centre. In other words, the distance of the earth from the sun does not vary greatly in the course of the year.

But in the case of Mars the elliptical orbit differs much from a circle. It is an oval, with the sun not at the centre but nearer one end of the oval. Hence the planet is nearest to the sun and the earth if the opposition occurs when the planet is at that end of its elliptical orbit. The earth is always in that line during August. And this is the reason why we get our closest view of Mars when the opposition takes place in August (Fig. 12).

Every fifteen years we have an opposition at or near that favourable position. At those times there is the best chance to detect faint details upon the surface, as Schiaparelli found in 1877.

Moreover, the closer the planet is to us, the more accurately can its distance from us be measured. For this reason, in September 1877, that great Scottish astronomer, David Gill, carried out to Ascension Island, in the Southern Atlantic, the instruments required for the purpose. He then settled to the satisfaction of astronomers

a perplexing problem as to the true distances, in miles, of all the planets and the sun.

The result reached by Sir David Gill in 1877 remained the best known until, ten years later, as her Majesty's astronomer at

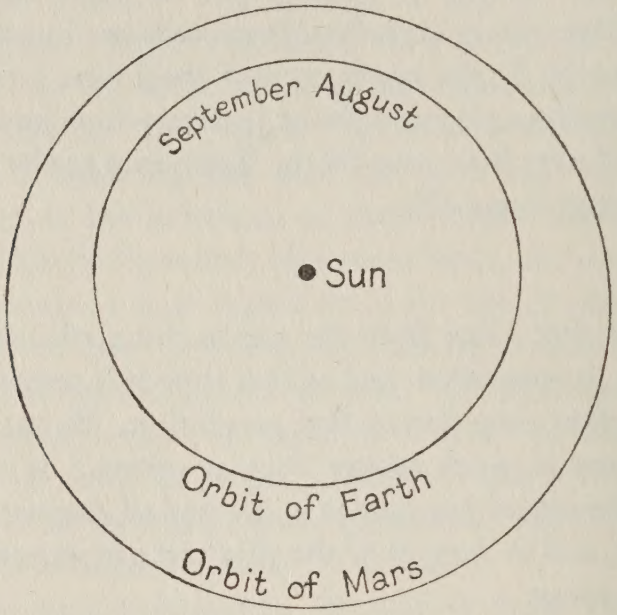

FIG. 12.—To show the excentricity of Mars' orbit and position of Earth in August and September

the Cape of Good Hope, with more powerful appliances, and with all the experience gained in the interval, he measured the sun's distance still more exactly, and in doing so performed a feat of accurate observation which stands out even to-day as one of the greatest triumphs of British astronomy.

Those of us who look out for the fiery red planet in the south after 9 P.M. during any opposition of Mars, which occurs every two years, will perhaps have an increased interest when bearing in mind what has been told in this chapter. Unfortunately the best oppositions of Mars occur when it is in a part of the ecliptic which never reaches a great height above the horizon in our latitudes.

We are not likely ever to receive messages from Mars. But to most people there is a perennial interest in discussing what at present is a question with no immediate prospect of solution, the habitability of the planet Mars. All that can be said with certainty is this : if human beings can exist on any planet, Mars is the one on which they would have the best conditions for their existence.

CHAPTER V

KEPLER'S SOLAR SYSTEM AND NEWTON'S LAW OF GRAVITATION

I

THE finest emotions are stirred within us through astronomy, not only by the wonders of creation, but also by the intellectual powers, the patient perseverance, the unselfish devotion and the outstanding humility of those wonderful pioneers who have handed down the torch of knowledge from century to century, whose beautiful lives are the envy of all true lovers of the stars.

The one and only ruling principle of the universe, whose truth has been established, and whose application is universal both in time and space, is the attraction of gravitation, according to laws which, so far as we can be sure, are of the utmost simplicity.

This was the work of three men : Tycho Brahe the Dane, Johann Kepler the Pole, and Isaac Newton the Englishman. Their lives, their laborious toil and their triumphs will remain an incentive to inquiring effort so long as the world shall last. Their aim was the solution of the riddle of the solar system ; and the complete solution of this puzzle involved the marvellous discovery of universal gravitation.

Everybody knows that a rough model of the solar system can be made by putting a ball in the middle of a flat table-top, to represent the sun. A circle drawn upon the table, with the sun as centre, represents roughly the earth's orbit, and you can divide the circle into twelve sections, and mark upon each section the month during which the earth occupies that section. The constellations of stars, on such a model, would be far away, beyond the walls, ceiling and floor of the room. They are used by astronomers as fixed directions in space, with which to compare the direction of any observed line of sight from the earth to the sun or to a planet. The zone of stars and constellations that would be cut by the table-top if it extended so far are called ecliptic stars, and signs of the zodiac.

The names of these constellations of the ecliptic, called signs of the zodiac, if remembered in their proper order, are a great help towards recognizing other stars.

They are :

Aries *Taurus* *Gemini*
The Ram, the Bull, the Heavenly Twins,
Cancer *Leo*
And next the Crab, and Lion shines
Virgo *Libra*
The Virgin and the Scales,
Scorpio *Sagittarius* *Capricornus*
The Scorpion, Archer, and He-goat,
Aquarius
The Man who bears the Watering-Pot,
Pisces
The Fish with glittering tails.

Orbits of other planets than the earth would be represented by circles : Mercury and Venus smaller than the earth's circle ; Mars, Jupiter and Saturn, besides the telescopic planets Uranus and Neptune, all being outside the earth's circle (see Figs. 8 and 9, p. 37).

The planets and the moon are always seen very close to the ecliptic line among the stars.

The radii of the circles for different planets are in the following proportions ; the period of revolution is also given, and their diameters:—

	Distance		*Period*	*Diameter*
	True	*Bode's Law*	*Years*	*Miles*
Mercury . .	4	4 + 0 = 4	0·24	3,030
Venus . .	7	4 + 3 = 7	0·61	7,700
Earth . .	10	4 + 6 = 10	1·00	7,918
Mars . .	15	4 + 12 = 16	1·88	4,230
Minor Planets .	...	4 + 24 = 28	...	...
Jupiter . .	52	4 + 48 = 52	11·86	86,502
Saturn . .	95	4 + 96 = 100	29·46	73,000
Uranus . .	192	4 + 192 = 196	84·02	31,900
Neptune . .	301	4 + 384 = 388	164·79	34,800

PLATE II.—OPPOSITIONS OF JUPITER DURING TWELVE YEARS, IN ALL OF THE SIGNS OF THE ZODIAC

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Bode's law fails entirely for Neptune, but is useful to help the memory for recalling roughly the planetary distances. Remembering that the earth's distance from the sun (taken at 10 in the Table) is ninety-three million miles, the distance of any planet from the sun can be got from the Table in miles.

There is no better plan for learning the ecliptic path among the stars than the practical plan of tracing the motion of the planets among the stars.

Jupiter is "in opposition" to the sun every thirteen months or thereabouts. He is then due south of us at midnight. But at each

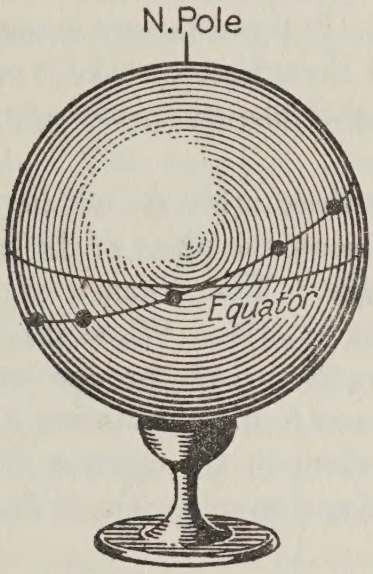

FIG. 13.—Jupiter's position at successive oppositions among the Stars, marked on a celestial Globe

opposition his elevation above the horizon is different. So, in the course of some twelve years, we can draw twelve pictures of the position of Jupiter in opposition among the constellations of the zodiac, keeping the celestial equator always in the middle of the picture (Plate II.).

Placing the twelve pictures side by side (Plate II.), it is immediately evident that Jupiter, during one revolution, has occupied places on a regular curve, but this curve is not the Equator. It is sometimes to the north, sometimes to the south, of the Equator.

If these places be marked by wafers on a celestial globe they are

found to lie all on a great circle—*i.e.* on a plane surface going through the centre of the globe (see Fig. 13). This is almost exactly the ecliptic, or path of the sun among the stars.

Returning to our table-model of the solar system, and looking down on it as from the northern part of the heavens (say from the Pole-star), a line from sun to earth would revolve through the constellations of the zodiac in the opposite direction to the motion of the hands of a clock. The same rule applies to all the planets and most of their satellites ; and also for the direction in which planets rotate on their axes.

The model can always be visualized as a memory when thinking about the solar system. It is satisfactory enough for some purposes, but it needs two small alterations to make it more accurate.

The first fault is that planets' orbits are not in reality quite circular.

The second is that these orbits do not lie exactly on the plane table-top, which represents the plane of the earth's orbit.

To take an example. The distance of Mars from the sun varies at every part of its orbit. When the line from the sun to Mars, produced onwards, passes through the constellation Leo, its distance from the sun is then about one hundred and fifty-five million miles. But when in the opposite direction, in *Aquarius*, it is only one hundred and twenty-eight million miles (see Fig. 12, p. 56).

Again, Mars' orbit should not lie, in our model, exactly on the table-top, but the table would have to be tilted nearly two degrees about that line through the sun which points to the constellation *Aries* on one side and *Libra* on the other. Then the model would show the true path of Mars. So can the true path of each planet be rectified on the model.

II

In the author's little *History of Astronomy*, and in most text-books, it is told how Copernicus (born 1473) brought evidence in favour of Pythagoras' explanation of a planet's retrograde motion when in opposition. It depends on the supposition that each planet moves in a circle round the sun, revolving with uniform velocity, the more distant planets moving slower then the earth. The same

book tells how Tycho Brahe insisted that no true theory of the solar system could ever be reached until an accurate, continuous and prolonged set of observations of planetary positions had been made. Also how he made these observations. And how Kepler made use of them to establish three laws of the planetary motions. And how Newton proved that these laws could be stated as a single law of force, universal gravitation, between every two particles in the universe. And thus Tycho Brahe's observations led to the greatest law that has ever been discovered about the physical universe. THERE IS AN ATTRACTIVE FORCE BETWEEN EVERY TWO PARTICLES OF MATTER WHICH VARIES DIRECTLY AS THE PRODUCTS OF THEIR MASSES AND INVERSELY AS THE SQUARE OF THE DISTANCE BETWEEN THEM.

It is not intended here to enlarge on the stupendous importance of Newton's discovery. This has often been told before. What is now about to be told is a story of transcendent interest that has seldom been mentioned. It is unlikely that more than a few readers of these pages know about it. I cannot find it in the text-books.

It is the story of how Kepler took hold of Tycho Brahe's continuous records, during twenty years, of the directions among the stars in which Mars and the sun were observed from the moving earth ; and how he was able from these to trace out, as on our table-model, the shape of the earth's orbit and of Mars' orbit, their relative sizes, and the exact positions of these planets upon their orbits at different dates.

Until Kepler's time everyone had assumed, without any reason, that each planet must move in a perfect circle with perfectly uniform velocity. Kepler's declaration was this : " I won't assume anything, except that the planets revolve in fixed orbits round the sun, and I will solve the problem of their orbits and speeds from Tycho's observations."

How did Kepler solve it ? It was only by reading Kepler's beautiful book when I was over forty years of age that I made the great discovery of how the problem could be solved by his ingenuity. It is not probable that more than one or two per cent. of our best astronomers or mathematicians could readily give a solution to the difficulty without help from Kepler's book ; and, unfortunately, there are very few who do read it. I have tried to find one such

man among my own scientific friends. As yet I have not found one who could see even how to begin. Just consider the difficulty of finding the place of Mars on an unknown orbit by means of observations from the earth, also lying on an unknown orbit.

The best suggestion I ever got as to how Kepler could have done it was from a past President of the Royal Astronomical Society, who suggested that Kepler began by guessing the orbits and velocities, and noting the errors involved in his guesses, and then trying again. And so on, till he found an ellipse with the sun in its focus, and the planet revolving at such a speed that a line from sun to planet covers equal areas in equal times. This would have been a hopeless task, and it was not Kepler's plan.

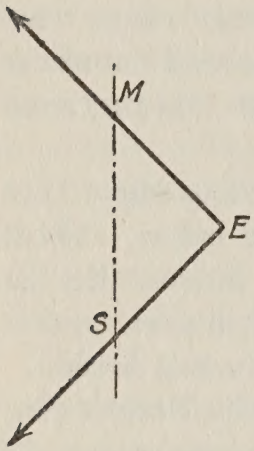

FIG. 14.—The directions from Earth to Sun and Mars being known, if only we knew the direction in which Mars would be seen from the Sun, then the shape of the triangle S–E–M would be known

Kepler made no guesses. He invented a mode of attack that was infallible. It was a trick. And, like Columbus and the egg, when once the trick is known a child can understand it.

The first artifice that Kepler invented for this purpose was to take advantage of the fact that Mars completes a revolution round the sun, and returns to the same position every 687 days. Then, from all the dates on which Tycho had observed the direction of the sun and of Mars among the stars, Kepler was able often to choose two that were almost exactly 687 days apart, and he could easily estimate the correction required to complete exactly the 687 days, or one complete revolution.

If now he had known the exact form of the earth's orbit, and the earth's place on it on these two dates, this would have been a base-line. He also knew the angles by which any surveyor could mark on a plan the exact distance of Mars, and its place compared with the earth and sun.

So he would then be able to map out the orbit and positions of the planet all through its revolution. Only one thing was lacking : he did not know even the shape of the earth's orbit.

So his difficulty was now reduced to finding out a number of points on the EARTH's orbit from the Mars observations.

The observations at any date enabled him to draw on paper, from a point to represent the earth's place, two lines to stars in the zodiac representing the direction of lines from the earth to the sun and to Mars, as shown in Fig. 14. If only he could tell the direction of a line from the sun to Mars, then any line such as S M parallel to that direction and cutting the other two lines would make the shape of his triangle quite clear, and he would know the comparative distances of the sun, Mars and the earth from one another. It was here that Kepler's greatest ingenuity appeared, in finding the direction of the line from the sun to Mars.

III

[This section—of surpassing interest to most astronomers—may be too technical for general readers, who should now pass on to Section IV., p. 65.]

Kepler's Discovery of the Earth's Orbit

Kepler noticed that THERE IS ONE DATE IN EVERY TWO YEARS OR SO WHEN THE DIRECTION OF THE LINE FROM SUN TO MARS WAS KNOWN FROM TYCHO'S OBSERVATIONS. For at opposition this line is the same as the line from sun to earth, and is known. Tycho had observed oppositions of Mars on the dates :

Year	*Date*	*h.*	*m.*	*Year*	*Date*	*h.*	*m.*
1580	Nov. 17	9	40	1591	June 8	16	25
1582	Dec. 28	12	16	1593	Aug. 24	2	13
1585	Jan. 31	19	35	1595	Oct. 29	21	22
1587	Mar. 7	17	22	1597	Dec. 13	13	35
1589	Apr. 15	13	34	1600	Jan. 19	9	40

At any one of these oppositions S E and M would then be in one line (Fig. 15).

Take S M as the distance from sun to Mars at the date of an opposition. On that scale we want to find the earth's orbit. Six hundred and eighty-seven days later S and M would be in the same places as before, and the earth would be in some unknown position on a known line S e. The direction of Mars as seen from the

earth is known from observation. All we have to do, then, is to draw, through M, a line parallel to that direction to cut S e at some point E_1. The earth lies on both of these lines, so it *must* be at E_1. Thus E_1 is fixed at a certain date. So, at farther intervals of 687 days, the place of the earth is marked by points E_2, E_3, E_4, etc. And other oppositions give intermediate points on the earth's orbit. By using this device Kepler discovered the orbit of the earth.

Having now a plan of the earth's orbit round the sun, and its place at all dates, any two observations of Mars 687 days apart

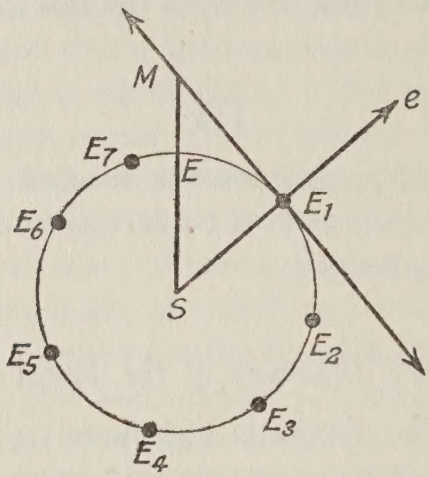

FIG. 15.—Showing how Kepler was enabled to trace out the orbit of the Earth

give one point on the orbit of Mars by the ordinary methods of a surveyor. So Kepler was able to trace out the orbit of Mars ; and he found it to be very different from a circle. It was an ellipse, with the sun in one focus ; and a line drawn from the sun to Mars was found to pass over equal areas in equal times.

Thus a problem which would otherwise be insoluble was made quite simple by the device of starting from some date when Mars was in opposition and making comparisons with observations at intervals of 687 days.

Kepler had now discovered the great law of elliptical orbits, which was found to apply equally well to all the planets. After that it was easy to find the exact position of the imaginary plane surface on which the elliptic orbit of Mars (or any planet) lay, tilted to our model table-top.

To do this Kepler again made use of Tycho Brahe's observa-

tions of Mars when in opposition. Referring back to Fig. 10 (p. 48), it is seen that, during the period of opposition in 1924, Mars was travelling in *Aquarius* south of the ecliptic, reached a maximum in July, and by November was nearing the ecliptic. The amount of this maximum divergence from the ecliptic was greatest when Mars was in *Cancer* and *Capricornus*. From such observations Kepler found that Mars' orbit was inclined to the

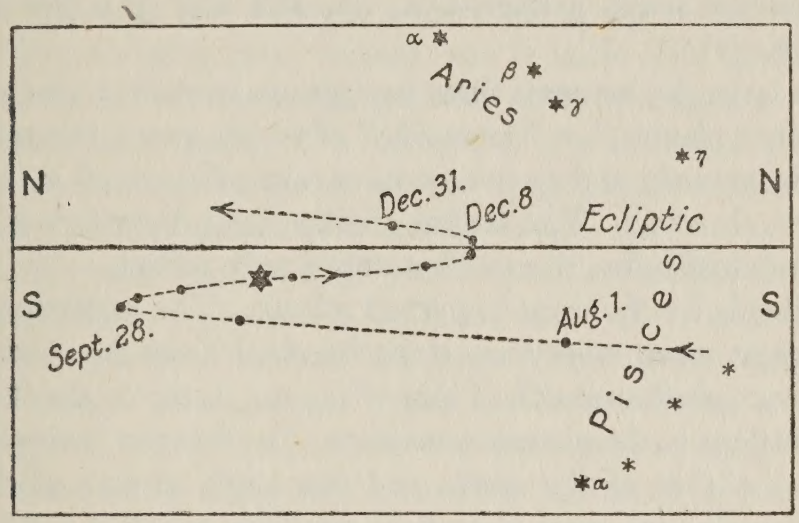

FIG. 16.—Retrograde motion of Mars in 1926. The opposition is marked by a sign ★, 16th October. Thus Mars when in Aries is moving across the Ecliptic from south to north

earth's nearly two degrees, for he now knew the distances from each other of sun, earth and Mars, and could easily make this calculation.

And if now we plot in the same way Mars' path among the stars at the opposition of 1926 (Fig. 16), the planet is seen to cross the ecliptic in *Aries*. So Kepler was able to find the line on our table-model about which the plane has to be tilted to be in the plane of Mars' orbit. These beautiful devices of Kepler have received far too little mention in the text-books of astronomy.

In the author's little *History of Astronomy*, and far better in Grant's magnificent *History of Physical Astronomy*, the reader can learn how, starting from Kepler's laws, Sir Isaac Newton was led to the great law of universal gravitation, and how he applied it to explain scores of riddles of the solar system.

IV

The planets of the solar system consist mainly of two groups of four. There are four small planets—Mercury, Venus, the Earth and Mars—at mean distances from the sun in the ratios of 4, 7, 10, 15, that of the earth being 10. There are also four large planets—Jupiter, Saturn, Uranus and Neptune—whose distances are much greater—52, 95, 192 and 301 (see Figs. 8 and 9, p. 37).

The large gap between these two groups contains a vast number of "minor planets," or "asteroids," of which over a thousand have been discovered; eighty-five of them were discovered in 1925 by eighteen observers. The largest of these have diameters of two or three hundred miles, the smallest only a mile or two.

Jupiter is far the most important planet. The attracting power of its great mass, more than three hundred times the earth's mass and about one-thousandth of that of the sun, is the origin of notable perturbations in the planetary motions. Its diameter is eleven times as great as that of the earth, and one-tenth of that of the sun. Only four moons were known to circulate round it until recent years. We now know of nine, which cannot all be seen by eye, but all of which can be photographed by prolonged exposure of the photographic plate.

The earth has one moon, Mars two very small moons, Jupiter nine. Saturn has nine moons and a stupendous enclosing flat ring —a marvellous sight in any good telescope. Uranus has four moons and Neptune one.

It is impossible for anyone to form a clear picture of astronomical distances. The best we can do is to try to proceed by steps. We all know about the distances covered by a railway train going at fifty miles an hour. It takes eight hours to cover the four hundred miles between London and Edinburgh. It would take sixty times as long, or twenty days, to go round the earth. This train would reach the moon in a little over six months. But to reach the sun, two hundred and twenty years would be required.

It is clear that for planetary distances we must change our point of view from the sluggish railway train. A cannon-ball can travel at 2500 feet a second, say a mile in two seconds, and, if it could

keep up the pace, it would get from London to Edinburgh in less than a quarter of an hour. But it would take six years to reach the sun, thirty-one years to go from the sun to Jupiter, and one hundred and eighty-three years to Neptune, the outermost known planet. To cover the space to the nearest fixed star a cannon-ball would take over one and a half million years.

It appears, then, that when we pass from planetary to stellar distances we must take a faster speed than a cannon-ball. Light travels 186,000 miles every second, and it takes eight minutes to pass from the sun to the earth, and four hours to Neptune. This means that if an eruption of a sun-spot or a prominence occurred suddenly on the sun, we should not see it until eight minutes after it happened. Inhabitants of Neptune would have to wait four hours. Light takes four and a half years to pass from Alpha Centauri, the nearest fixed star, to us. A light-year is 186,000 miles multiplied by the number of seconds in a year. Most of the stars are so far away that, if any outburst occurs on one of them, as sometimes happens, and if we perceive the outburst, we may be sure that the event really happened hundreds or thousands of years ago. Lately some astronomers have noticed variations in the light of stars in the great nebula of Andromeda, which enabled them to estimate with some sort of probability that these variations which they are now examining actually occurred nearly a million years ago.

So much for astronomical distances.

V

As a final illustration of Newton's law of gravitation, which holds for small things as for great, let us make a model of the solar system to scale, and then consider what would have to be done to make it into a *working* model.

Take a globe nine feet in diameter, made of very hard wood, like ebony, that sinks in water, for the sun ; then take balls about half-an-inch in diameter for Mercury and Mars, and one inch for Venus and the earth. All of these should be made of our lighter metals. The ball representing Jupiter would have a diameter of 11 inches, Saturn 9 inches, Uranus and Neptune each some 4 or 5 inches

in diameter, all of these being made of hard wood except Saturn, which would be of cork.

Now place them on the ground all in a line at the proper distances, on the same scale. From the nine-foot ball to Mercury is 110 yards, to Venus 180 yards, to the earth 280 yards, and to Mars a quarter of a mile. The larger balls are Jupiter at three-quarters of a mile away, Saturn one and a half miles, Uranus three miles, and Neptune on this scale would be four and three-quarter miles from the nine-foot globe.

If the nine-foot ball, for the sun, were placed in Piccadilly Circus, London, at the Swan & Edgar corner, then, going westward for the earth's position, you would have to go past Piccadilly Place, past Swallow Street, past Vigo Street, past the Albany, to Burlington House. There you would lay on the pavement the one-inch ball for the earth ; and so on with other planets, until you place Neptune, a five-inch ball, some five miles away, at Hammersmith.

Having now got our model solar system on a scale of a little over six hundred million to one, we want to imagine it as a working model. Give, by any means, to the one-inch ball, that represents the earth, a velocity at right angles to the line of models of one five-hundredth of an inch per second, and certain other definite velocities to the other balls.

Now, wonderful to relate, if only the whole world, upon whose surface these balls have been laid, could be annihilated, then these balls would be acted on only by the force of gravity between them, and, by Newton's law, it would be found that the nine-foot ball in Piccadilly Circus would cause the one-inch model of the earth, starting at Burlington House, actually to revolve round it, because of its gravitational attraction, once in a year. And so with all the other bits of metal and wood and cork, if they had been started with the proper velocities. And the five-inch model of Neptune five miles away would revolve round the nine-foot globe in one hundred and eighty-six years.

Perhaps this statement, which at first sight seems very wonderful, if not incredible, may help some readers to regard gravitation as a reality rather than an abstraction.

CHAPTER VI

THE MOON

I

THERE is no object in the heavens that appeals to us more as the source of beautiful thoughts than the moon. The points of view from which she is regarded by the astronomer, the philosopher, the mathematician, the poet, the lover, the artist, or the practical man, all beautiful, are as diverse and varied as her own phases.

Reborn every month, she first appears as a delicate crescent, two days old, in the amber light of sunset, a reincarnation grasping in her arms the shade of her prior existence, the old moon in the new moon's arms. At the age of seven or eight days her face is a sharply cut half-circle of white. Then she takes on that curious form "gibbous," until at the age of fifteen days she dominates everything in heaven and on earth, as the full moon, round, bright and glorious. Her declining days have an air of dissipation and decadence when exposed to our gaze during the forenoon hours, until she is lost in a beautiful second childhood before the hour of sunrise, and dies at the age of thirty days, to be again reborn.

But it is not only in her changing phases that the moon is an object of interest. There is nothing else in nature quite like the strong shadows cast upon our path by the moon. There is nothing quite like its reflections from the ripples of a lake, or from the waves of the sea during a long voyage.

On a night of full moon the spirit is uplifted, and many are they who repeat to themselves the thoughts of Lorenzo :

> "The moon shines bright : in such a night as this,
> When the sweet wind did gently kiss the trees,
> And they did make no noise,—in such a night"

was the soul of many a hero stirred to start upon an historic adventure which is now an epic poem. On such a night, in the lives of most of us, did some event occur, that now recalls some thrilling incident of our youthful enthusiasms.

The moon is an inspirer of memories to everyone. Furthermore, she is a true guide to the traveller, a lamp of hope to the

way-worn, and of safety to the mariner, an inspiration to the poet and the musician, and, marvellous gift, she is the one connecting bond with his own people to the exile or prisoner in distant lands, the one visible object of common delight to him and them. I have known this to be true ever since, fifty years ago, I heard this plaintive utterance, on the shores of Lake Baikal, from the lips of a Scottish girl, herself an exile for life in the wilds of Siberia.

In another mood our thoughts about the moon turn to the tides, raised and driven by the moon's force of gravitation, with which our luminous attendant sweeps and scours the estuaries and ocean shores, as a scavenger, safeguarding the health of millions.

And again, we are attracted by the intellectual problems about the moon's constitution, her motion round the earth, and the very origin of this cold round globe, illuminated by the sun. Add to this the wonder and speculation aroused by seeing the moon through a telescope, displaying the extraordinary features that characterize her surface.

II

Those people who examine the sky at night, not only with wonder or admiration, but also with intelligence, take note of many things worth remembering. If the moon to-night at a certain hour is in a certain part of the sky, then to-morrow it will be more to the left at that hour (for us in northern latitudes). And three-quarters of an hour will elapse before it reaches the same region as last night.

Again, the intelligent spectator can note that this wandering of the moon is over a definite course among the stars, much the same as the sun's course, passing near the very bright stars of the ecliptic, Aldebaran, Regulus, Spica and Antares. In fact, these stars are sometimes "occulted" or eclipsed by the moon. During the year 1924 Aldebaran and Regulus were occulted by the moon, each six times. Astronomers take delight in watching these disappearances and reappearances even without a telescope.

The age of the moon regulates the hours during which we need no lantern to go home with in the country. A knowledge of the moon's age tells us when yachting at what hour it will be easy to make a landing. If you think of spending an evening with your

telescope you avoid any night when the moon is near the full. It is often good to know when to expect spring tides—that is to say, when the moon is new or full. In fact there is no need to labour the point that even in peace time, when there are no air raids, we often want to know the age of the moon.

Fortunately there is a rough-and-ready rule, easily remembered, by which the moon's age at any date can be foretold.

Here is the rule. There are three numbers that have to be added together to give the moon's age. If ever the sum exceeds thirty, the moon's greatest age, you subtract thirty. The remainder is the moon's age at that date.

The three numbers are called the year number, the month number, and the day number.

(1) *The day number* is simply the day of the month.

(2) *The year number* in 1911 was 0. For each year after 1911 you add 11. When the number exceeds 30, you always subtract 30. For example, take the year 1924. That is 13 years since 1911; and 13 elevens is 143. This is the year number after you have subtracted 30 four times, or 120. This leaves the year number for 1924, and it is 23. Once found, it serves you throughout the year.

(3) *The month number* is best remembered thus: Write on one line the initial letter of each month, and below each month the following month numbers:—

J	F	M	A	M	J	J	A	S	O	N	D
0	2	0	2	2	4	4	6	7	8	9	10

After reading the row of numbers aloud several times *in pairs*, their sequence is easily remembered.

As an example, take the 17th of July 1924:

Year number	= 23
Month number	= 4
Day number	= 17
Sum	= 44
Subtract	30
Moon's age	= 14 days

This is one day short of full moon (fifteen days).

On testing this rule by the almanac you will find it to be always right, within a day. The rule has been very true for the last fifty years. There will be closer accuracy for the next fifty years if the year number be always increased by adding 1 to it.

In many other directions the ordinary observant person finds out things concerning the moon's motion. The full moon rises to a greater height in the sky during winter than in summer—just the opposite to what the sun does. It does not take long to realize the wonderful fact that the moon always presents to our view the same half of her spherical form. We can always recognize the same markings : the dark eyebrows of the man in the moon and his smudged mouth, while the tip of his nose is always seen near the middle of the full moon. No person has ever seen the other side of the moon. This is one of the things that are difficult to explain ; and the reason usually accepted is so far from being entirely satisfactory that we must at present make no attempt at explanation beyond saying that it is supposed to be due to tidal friction in a previous age when there were tides on the moon.

III

A matter of far greater immediate interest is to examine the features of the moon's surface, for there is no object in the heavens that offers more beauty and wonder to us than the moon in her different phases. And this is true whether we look at her through a small spy-glass or through one of the greatest telescopes in the world. A common field-glass reveals new and unexpected details ; and every increase to the power of our telescope increases the wonders of this new world.

We might expect to see a close resemblance to the features of our earth, with its oceans and continents and vast mountain-ranges. These are all absent, and we feel that we are looking at a dead world in ruins.

Looking through a telescope at the full moon it is easy to see that the general outlook is upon two types of scenery. Around the poles, especially at the southern pole, the surface is white as snow, but round a great circle on the moon, near to, but not actually on,

its equator, the surface is black as the ice on a newly swept curling-pond. There is, however, a further feature of the most extraordinary nature. In the southern snow-cap, one of the largest of those white ring-shaped mountains, usually called "craters," is Tycho. Its position can be easily noted, because that point is the centre of a star-shaped set of wonderful streaks or cracks, reminding us of the star-shaped cracks on a frozen pond, when a skater has fallen and cracked the ice. These "Tycho streaks" extend to great distances, almost right across the whole surface of the moon, and are most distinct at the full moon.

These are the three things that strike the eye in the first look through a telescope at the full moon—the great surfaces white as snow, the black belt like clean ice, and the streaks like ice-cracks.

The whole of the white regions are broken up and disturbed, and covered with lunar craters, whose shapes can be best examined when the moon is a good deal less than full.

The zone of black regions is one whose pole would come somewhere near to the crater Tycho, which is the centre of the streaks. The whole of this zone has the appearance of a succession of large, calm, level and generally circular seas, separated from each other by white rough boundaries. A simple glance establishes the circular form of some of these—the sea of Crises, the sea of Nectar, the sea of Serenity and the sea of Showers. They have been called seas, as the ring-mountains have been called craters, without good reason from terrestrial analogies.

The moon's temperature is far too low to permit the presence of liquid water. Nor is there any air ; at least, Bessel proved that its density cannot exceed the nine-hundredth part of our own atmosphere.

When we look with a telescope at the moon in the first quarter, or in any phases except full moon, our attention is engrossed with wonder at the forms of the lunar craters in the snow-white regions. In fact, it is probably true that to the amateur astronomer there is no more attractive object in the heavens than the weird shapes of those craters which lie near the boundary between the illuminated half of the moon and the half that is in shadow. It is then possible to judge from the shadows cast by the sun how high, steep and rugged are the walls of these craters, in some cases miles high.

The shadow of the crags on one side falls upon the floor of the crater. Often it happens that the sunlight reaches only the summits of the peaks inside the crater, and they then appear as bright spots on a dark, unseen background (Plate III.).

The most common features of these craters are the flat floor, level with the general surface of the moon, the ring of crags enclosing it, and a hill or cone rising out from the centre of the floor. But the variations from this type are innumerable. They vary much in diameter and in the heights both of the crags and the central hill. Every stage of transition from the typical form can be traced until we find, in the whitest regions near Tycho, mere holes pierced in the surface showing no floor, no central cone, no surrounding ridge.

In some regions near to Tycho and the south pole the craters are unusually abundant, and so close together that the enclosing ring of one may be either deflected or obliterated at one side by another encroaching crater.

Those who have not the opportunity of studying these marvels through a telescope can do almost as well by securing copies of the wonderful photographs from the great observatories of the world, in which every detail can be examined. But, best of all, they can look at the splendid atlas of the moon by the French astronomers, Puiseux and Loewy, who have published copies of their beautiful negatives, enlarged so that the whole diameter of the moon is six feet across.

All the seas and craters and mountains on the moon have had names given to them. It is a pleasant occupation to take a lunar chart and a small telescope and to identify these features.

When this occupation has familiarized us with the craters and the Tycho streaks and the seas and mountains, the question must arise : How have these formations been made ? On our own earth, geologists refer us to denudation, glacier-action and volcanoes, as being responsible for the mountains and valleys. On the moon the temperature is so terribly low that denudation by water is out of the question.

[*Mount Wilson Observatory*

PLATE III.—"CRATERS" OF THE MOON

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IV

At present there is no theory for the moon that has gained general acceptance. The old idea was that the ring-shaped craters are really volcanic craters like those on our own earth. Now, however, those who are best acquainted with our own volcanoes find that, in essential features, there is a total dissimilarity, and that theory has been generally abandoned.

Other people have suggested that the craters were formed by aerolites falling from the sky and digging themselves into the level surface, throwing up the excavated material in a ring. The shell-holes in France, during the Great War, suggested this explanation, but in many points it fails entirely.

The shapes of these ring-formations, with a central cone, recall to the minds of many people the instantaneous photographs which have been taken, with great skill and ingenuity, of a drop of water falling into a bowl of water. The ring is formed momentarily, and also the central cone.

These thoughts have led some people to experiment with splashes, as by throwing a ball of clay on the floor. This certainly does often give the required shapes. But it cannot yet be called a theory of the lunar craters.

Most theorists have dealt only with the craters. And yet, surely the white streaks that radiate from Tycho across the moon must hold the key of the problem, at least in part. They stretch across the globe straight on, like a Roman road, regardless of hill and dale, unmoved by the presence of countless craters on the way. These are ruthlessly broken through by the terrific forces that must have been at work to produce these cracks. We are compelled to look for some great cataclysm.

There is one other theory of the moon that has often been brought forward. It has certainly not been generally accepted. But, seeing that there is as yet no accepted theory, we may devote a short time to the ice-and-snow theory.

More than once has the speculation been advanced that the moon is a ball of ice and snow. The pure whiteness of snow and blackness of smooth ice, and the white starry cracks radiating from Tycho, are certainly suggestive. And travellers in India who have

seen the full moon rising over the snow-clad Himalaya ranges have said that the equality of whiteness left them in doubt for a moment whether the moon were not a part of the snow-mountain range.

A theoretical argument has lately been put forward. The moon is supposed to have been broken away from the mass of the earth when molten. Both cooled down, but the smaller moon cooled quickest. So now, while the earth has a moderate temperature, that of the moon may be as low as the temperature of liquid air. If it once had lakes or oceans they all must now be frozen hard and solid.

Again, we have every reason to suppose that the moon is made of the same materials as our own planet, including some water, though it is now frozen. And sound reasons have been put forward for believing that the moon had a greater percentage of water in its constitution than the earth.

The mass of the earth is composed partly of rock and metals, which are heavy, and partly of water, which is light. Now, the mean density of the moon is only half of that of the earth. Therefore, in the moon, the proportion of water must be much greater. In fact, it is easy to calculate that, if this be the sole cause of the moon's lightness, the depth of her oceans, before they froze, must have been nearly four hundred miles, all over her surface.

It then would seem that, before the moon had cooled so much, the whole of its solid nucleus was immersed in water. These are some of the considerations that led to a snow-and-ice theory, as a vague suggestion. It is described by Puiseux and Loewy in the volume accompanying their lunar atlas.

These writers, when describing the snow-white surfaces surrounding the poles of the moon, add these words : " But it is also favourable to the opinion of those who consider that the poles of the moon are actually covered with ice. This opinion can be pushed even further by arguments that are plausible enough. It responds, in part, to the conditions actually realized on the earth and probably on Mars." They go on to say that the absence of any boundary between the polar-caps and the rest of the surface has led some people to the conclusion that the north and south ice-caps are joined so as to envelop the whole globe in ice.

There is an obvious criticism of such a theory when we realize that, while during one fortnight any place on the moon is subjected to an incredibly intense cold, yet during the next fortnight it is exposed to the blazing direct heat of the sun. We ask whether this heat would not raise the temperature of the ice to melting-point, and transform the whole appearance of the moon.

There are many reasons why we could hardly expect to perceive any such changes in the lunar configurations. In a rare atmosphere (as on the Himalayas) snow does not melt into water, but evaporates in vapour, as camphor does. Then this must be redeposited on the mountains of the moon, as it is on the snow-peaks of the Alps. But, most important, the disappearance of any mass could not be detected by our vision unless the mass that was melted had a diameter of many miles. So that centuries might elapse before any change could be seen.

The time has now come to give vitality to this rather vague theory by describing an experiment for reproducing the appearance of lunar craters.

V

One winter morning in the Highlands, at an altitude of seven hundred feet, with nearly twenty degrees of frost, a thin coating of snow, a quarter of an inch deep, was seen to cover a flat board that lay on the lawn. A snowball was made and thrown down with great force upon the board. What was the result? The snowball broke up and scattered radially over the board, sweeping the snow outwards to form a rampart, a ring-shaped steep ridge of irregular height. The floor was swept clean, and the remnants of the snowball were piled into a cone in the middle. The resemblance to a normal lunar crater was perfect.

The experiment was repeated under different conditions. By breathing on the snowball during its making it was as hard as ice. Then it could be thrown obliquely. Again, the thickness of snow lying on the board could be varied. These variations in the experiment produced new effects, and it was soon apparent that almost every type of lunar crater could be reproduced in this manner. If the snow were thick we reached the final phase where was no

scattering, only a hole in the snow, as we see on the moon in some regions near Tycho.

The experiment was interesting enough, but seemed to have no bearing upon the constitution of the moon. For how could we conceive that such mountainous snowballs could ever have fallen upon the lunar surface? Then unexpectedly a wonderful connection seemed to be possible between the lunar craters and the white streaks or cracks radiating from Tycho.

If the ice-theory deserves any attention, then surely these radiating cracks must indicate some catastrophe, by which the ice-crust of the moon was fractured, in the star-figure always assumed by cracked ice.

The explanation arose from considering the physical conditions following increasing cold upon the moon, a solid nucleus enclosed and submerged in an ocean hundreds of miles in depth.

When the temperature fell, the whole surface would become covered with a shell of ice. This shell would gradually thicken to a depth of ten, twenty, or one hundred miles or more, by the freezing of additional layers of ice on the inside of the shell.

Now, we all know that water expands in freezing. If, then, inside the shell, a new layer of ice is added by freezing, it expands. This must either burst the shell or compress the remaining water. In the earlier stages the shell would give way at the thinner regions near the hotter equator, and it is possible that these overflows might spread into large round seas before being again congealed. It is not impossible that the black regions of the moon were thus formed of smooth ice.

After the shell has thickened perhaps to a depth of one hundred miles or more, it may still be able to resist the enormous hydrostatic pressure that was exerted inside of it.

Finally, however, the accumulating water-pressure becomes insupportable. Then comes the cataclysm. The ice-cover gives way at its weakest point. This happened to be where now we have the crater Tycho.

The overwhelming pressure bursts the shell at that point and cracks the whole shell in star-shaped streaks, extending over half the globe. A large part of the contained water, oceans of it, are shot up, it may be thousands of miles, to the sky. Released from

[*Lick Observatory*

PLATE IV.—FULL MOON

Showing "Craters," "Seas" and Tycho-streaks

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the pressure, it all freezes instantaneously in masses that vary from the size of a raindrop to the size of a mountain ; and they fall back on the ice-surface of the moon. Nearly half the globe is by that time covered with a snow-layer, thick near Tycho, thinner farther away. And upon this coating of snow fall mounds and hills and mountains of frozen water, gigantic snowballs, falling upon the snow-covered, smooth surface, and repeating upon a gigantic scale the snow-splash of the experiment already described, producing all the various shapes of lunar craters.

As a result we see in a powerful telescope, or in the best lunar photographs, that the crater formations over half of the visible hemisphere, most numerous near Tycho, encroach on each other, and blot out those that had been first formed. And again near Tycho, where the snow is thickest, some of these great snowballs have simply buried themselves in the snow, leaving visible nothing but deep holes (Plate IV.).

Meanwhile the water which was left inside, having been relieved from the great pressure, instantaneously freezes ; and our moon remains permanently as a solid globe of ice containing a rocky nucleus, covered with snow over a great part, dotted all over with craters, with pit-holes in the snow, and with great black seas of virgin ice ; and, through it all, the star-shaped cracks radiating from Tycho, filled up almost to the edges with white ice, upon which, at full moon, the sun shines, and reveals to us those white streaks that have been a puzzle.

The records of Arctic travellers and Himalayan explorers in a rare atmosphere, concerning the surprising phenomena displayed by ice-formations on a large scale, gives an assurance that there is probably no lunar feature that is not reproducible in an ice-world. Most certainly the curious "rills" seen near the centre of the moon beside the crater Triesneckar are reproduced by the expansions and contractions of ice during great fluctuations of temperature on large frozen lakes in the north.

VI

It seemed desirable, in view of this novel speculation, to make a test, on a small scale, to see whether a globe of water frozen from

the surface inwards would give rise to an explosion like that at Tycho.

With the kind help of the late Sir James Dewar, an india-rubber balloon was filled with water and immersed in the intense cold of a bath of liquid air. This gave the required condition of freezing from the outside. The result was that, after three minutes, there was an audible "pop," as if the shell had burst. The india-rubber covering prevented any jet of frozen water from issuing. On removing the now solid ball, and breaking it up, it was found to be completely frozen to the centre. The experiment seemed to support the argument that an explosion like that at Tycho was inevitable.

Mr James Nasmyth, of steam-hammer fame, in an attempt to imitate the white streaks from Tycho, produced somewhat similar appearances on a glass globe by filling it with cold water, closing it up and plunging it into warm water. This causes the enclosed cold water to expand very slowly, and the globe eventually bursts, its weakest point giving way and forming a centre of radiating cracks similar to the fissures in the moon—Tycho's streaks.

And now the dream is over. We have allowed ourselves the pleasure of a speculative romance. Let no reader suppose that we have proved our case. A case has been stated for consideration of judge and jury, that is all. But the evidence must be sifted and examined far more minutely before it can be said that the ice-and-snow theory of the moon ought to be accepted.

Such speculations and guesses serve a useful purpose if they increase the interest with which you and I examine the remarkable features of the lunar surface. Still, after what has been said, a serious examination of De la Rue's most beautiful stereoscopic picture of the moon, as was, and perhaps is still, supplied by Messrs Beck of Cornhill, will be a new pleasure. For the impression becomes almost irresistible that suspended in front of you is a ball of ice, sprinkled with snow over some areas, with others left uncovered, dark ; and that it has been cracked, by a blow or otherwise, at the point where Tycho lies.

PLATE V.—GREENWICH OBSERVATORY

Showing Wren's Octagon Building, the 28-inch Telescope Dome, Transit Room (just showing) and Christie's Altazimuth. Magnetic House, in foreground, now removed

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CHAPTER VII

GREENWICH OBSERVATORY

I

THE situation for Greenwich Observatory in the park, on the summit of the hill, surrounded by foliage, was well chosen ; and the structure designed by Sir Christopher Wren, the friend of Sir Isaac Newton, and himself no mean astronomer, has an unmistakable charm. The building itself, as seen from the gates of the park, in its bold and comely outline against the sky, strikes a chord of harmony with the ever-present and ever-successful struggle in pursuit of the real eternal truth that has been waged within its precincts during an existence of two hundred and fifty years, under the reign of nine successive Astronomers Royal.

The most salient part of Wren's building is the wide octagon tower, surmounted by meteorological instruments and the time-ball, by whose fall at one o'clock the chronometers of our merchant-ships can be set, when they start from the Thames on voyages to all parts of the globe, for guidance in getting their longitude while at sea.

In contrast to this Jacobean portion of the edifice we also see from here Sir William Christie's great dome, enclosing the powerful 28-inch refractor—a feature still more suggestive of the astronomer's night-labours with the stars. The Oriental character imparted to this fine dome—by the overhanging of its spherical form beyond the building on which it rests—adds grandeur to our first view of this home of the oldest, the truest and most enthralling of all the sciences (Plate V.).

The modern part of the observatory, also due to Christie, is not seen from the park gates, nor until we have passed through the door in the old brick wall enclosing the grounds. These grounds include observatories, libraries and work-rooms, as well as the residence and garden of the Astronomer Royal.

On the first Saturday of June—the date has hardly ever been changed—the learned "Visitors," who have the right, under the Admiralty, to control the operations and policy of the observatory,

assemble in the great octagon-room of Wren's building, to hear the annual report of the Astronomer Royal.

On this "Visitation Day" invitations are extended to a large number of those concerned with the progress of astronomy. During the afternoon they are free to wander all over the place. When they inspect any instrument, or the room in which astronomical photographs are displayed, they find a courteous assistant on the spot, ready to supply all the information that may be sought.

Let it be supposed that the reader of these lines has secured this greatly valued privilege of inspection.

He enters that solid doorway in the brick wall, which is flanked by standards of length built into the wall on the left, and by the great Greenwich mean time clock, with twenty-four hours on the dial, on the right, a constant object of curiosity to the passers-by.

He finds himself in the open courtyard, facing both the residence and the octagon tower, with an outside wooden staircase to the roof. On his right are small observing huts, housing instruments generally for temporary observations. But on his left he is almost touching the wall that encloses the most important instrument in the world for fundamental astronomy of position, the Greenwich transit circle, located, where we now stand, on the zero of longitude for the whole world, the Greenwich meridian.

The passage to the left, between the transit-room and the eastern wall of the grounds, leads to the Oriental dome of the 28-inch telescope, and, farther on, to the great new building on the top of which are the 26-inch refractor and the 30-inch reflector.

Do you prefer to look at these, or to stay in the old part of the observatory, where are all the principal instruments for measuring time, and also the exact positions of the heavenly bodies ?

Most people would desire to see first the big telescopes used for magnifying and showing distinctly the markings on the sun, moon and planets, their satellites and Saturn's rings, the shapes of comets and nebulæ, and hundreds of millions of stars, some isolated, some in revolving pairs, some in clusters, and most of them massed in the star-clouds of the Milky Way.

These objects cannot be seen during this inspection, but we can have a look at the telescopes that are such a source of joy to the really keen astronomer.

There are two classes of telescope used by astronomers—"refractors" and "reflectors." The rays of light from a star which pass through the object-glass of a refractor are converged by it to a point at the focus, where they might be received on a sheet of ground-glass as in a photographic camera, and be examined with a magnifying-glass, or eyepiece. But the ground-glass is not wanted here, so the telescope consists essentially of an object-glass and an eyepiece. These are the important parts of a refractor. On the other hand, in a reflector, the light from a star which strikes the hollowed or concave surface of a speculum, or mirror, is also converged after reflection, to a focus. But, for examination by the eyepiece, these rays must first be reflected, by a second mirror, out of the telescope tube, to prevent the observer's head from shutting off the star's light from the speculum. This may be done in more ways than one. In the Newtonian design the observer looks through a hole in the side of the telescope tube towards a small diagonal mirror. In the Cassegrain design he looks through a central hole in the middle of the speculum towards a curved mirror in the axis of the tube.

The size of the telescope is usually stated as being the diameter of the object-glass or of the reflecting mirror. At Greenwich the largest refractor is the 28-inch. There are larger ones in America. At Lick Observatory the great refractor is a 36-inch. At the Yerkes Observatory of Chicago a 40-inch.

For larger telescopes than these, reflectors are always used. Lord Rosse's, in Ireland, was a 72-inch. So is the splendid one at Victoria, British Columbia. The only one in the world bigger than these is the 100-inch, at Mount Wilson, in California.

II

Let us now have a look at the great 28-inch refractor in the Oriental dome. Climbing the steps inside the building, we pass the chronometer-room on the first floor, with its heated chambers and its ice-cooled chambers, where chronometers and watches are tested for the Admiralty under varying conditions of temperature.

On the top floor we reach the great room with its spherical roof, left open over one segment of the sky by means of a shutter. The

whole of the dome is mounted to turn on a circular rail at the top of the wall. Thus, with very little effort, the open shutter can be brought in place, so as to expose any part of the sky.

Inside this room the huge telescope is mounted on a lattice girder frame which rests in an inclined direction that points up to the pole of the heavens. This girder is mounted upon pivots at the top and bottom so that it can turn about its axis. The telescope itself lies inside this girder framework, and is pivoted at its middle to the girder : thus it can be rotated so as to point to stars that are at any distance we please from the north pole of the heavens.

The girder, too, can rotate about its pivots ; and by these two rotations the telescope can be pointed to any star in the heavens. Only in the direction of the pole is the view obstructed in this form of mounting.

Lastly, the lower end of the girder is connected by geared wheels with clockwork mechanism that rotates the whole framework with the telescope at a regular speed to follow a star when, without this device, the telescope would be carried, by the earth's rotation about its axis, away from the direction where the star is, and the star would pass out of the field of view.

This mode of mounting the 28-inch refractor is extremely rigid. But the equatorial mounting of the other telescopes will be seen to differ from it, and to render the polar region of the sky accessible to our vision.

This splendid telescope has been of great service, especially in the study of a remarkable class of stars that are seen to be double, wherein the two stars are found to change their relative positions. A lengthy series of observations, extending through many years, has demonstrated that they are revolving round each other in elliptic orbits, as the planets revolve round the sun, but often taking hundreds of years to complete a revolution, instead of one year as our earth does.

This discovery of solar systems among the stars was one of many great discoveries in sidereal astronomy made by Sir William Herschel one hundred and fifty years ago. The telescope we are looking at is one of those that have splendidly carried on Herschel's work. Sir William Herschel's discovery was the first indication given us

that Newton's law of gravitation is universal, and that it extends beyond the solar system.

In some cases a study of these binary stellar systems has enabled astronomers to calculate the masses of the constituent stars. It is a remarkable fact, or coincidence, that the masses of the stars so far examined are, as a general rule, not very different from the mass of our sun.

The most difficult and, in the present state of accurate astronomy, the most desirable datum that is sought for is the distance of the stars. Now Mr Jackson, the chief assistant here, saw that if he accepted the above fact of equality of masses of stars as being generally near the truth, he would then be able to tell the distance from us of any binary system. In this manner he has calculated the distances of many stars with a greater probability of accuracy than others had been able to attain by more doubtful methods. In this and in many directions our great national observatory at Greenwich continues to maintain its splendid reputation of two hundred and fifty years.

In the days when I was a worker at the observatory, under Sir George Airy, the largest telescope was only a 12-inch refractor, in this same building now occupied by the 28-inch. At that time the dome was cylindrical in form, very ugly, like a gasometer. The bulging form given to the new dome has the merit of beauty, but it was really an ingenious device for making room for the much longer telescope.

III

Without further delay, let us now go to inspect the contents of the great new observatory which occupies the south end of the grounds.

This building contains not only two great telescopes, but also the accommodation required for the staff of assistants, in their daily occupations of calculating and summarizing the work of the observatory. It also contains the study, or office, of Sir Frank Dyson, the Astronomer Royal, a man who has proved himself here, as he had already done as Astronomer Royal for Scotland, at Edinburgh, not only a worthy upholder of the traditions of unrivalled accuracy and continuity bequeathed by his predecessors at

Greenwich, but a leader as well in the modern extension of outlook into the structure and evolutions of the stellar universe. Among his many activities his name will always be associated with his observations to discover the proper motions, magnitudes and distances of the stars, and the relation of their distribution to the plane of the Galaxy. It was mainly owing to his energy that, during the total eclipse of the sun in 1919, our British observers were enabled to prove that the rays of light from a star, while grazing the sun, are deflected towards the sun, out of their course in a straight line.

Entering the new building, we ascend the stairs and go first into the dome of the great Thompson equatorial at the top of the building.

The mounting of this double telescope differs from the 28-inch and follows a more usual type of construction. The polar axis, pointing to the pole of the heavens, is not supported at an upper pivot. It is held and directed entirely by a cast-iron pedestal on the floor which contains the driving-clock. At the top of the polar axis, and at right angles to it, is the declination-axis. The peculiarity of this instrument is that two large telescopes are mounted, one at each end of that axis, and by turning on this declination-axis each telescope can be directed to a star near the pole or at any angular distance from the pole. Each telescope serves as a counterpoise to the other on the declination-axis.

One of these telescopes is a 26-inch refractor ; the other is a 30-inch reflector. No description can afford the same satisfaction as a personal inspection by the fortunate person who is free of the observatory on visitation day.

Such a visitor will climb to the gallery that goes round the room. Standing up there, he can look down into the open mouth of the 30-inch reflector and see the light of the sky brilliantly reflected from the silver surface of the great mirror. The mirror itself is made of glass, ground to the proper shape, polished, and then silvered by placing it in a bath containing a silvering solution. After that the silver is polished.

The visitor on the gallery looking down the tube can also see the smaller reflector, which reflects the image of any heavenly body to the outside of the tube, and so to the eyepiece, or else to

the photographic plate. He can likewise see the hole in the middle of the mirror, through which, on the Cassegrain plan, the rays can be so reflected by a small mirror higher up in the tube.

This reflector has accomplished much splendid work, and one of its greatest triumphs was the discovery, by an assistant, Mr Melotte, of the eighth satellite of Jupiter.

Galileo discovered four conspicuous moons revolving round Jupiter. They form beautiful objects even in a small binocular —four dots all in a line with the planet. Of late years five more have been added, making nine in all. The fifth one revolves very close to the great planet. But the sixth and seventh, outside the others, were detected on photographs with great skill, for they are extremely minute (seventeenth magnitude).

It then became important, at Greenwich, to observe the exact positions of these two satellites, from night to night, so as to determine their orbits conformably with Newton's theory of gravitation. For this purpose the 30-inch mirror was resilvered and polished, and it was then used for the research on the sixth and seventh satellites. Mr Melotte, the assistant whose duty it was to take these photographs in hand, noticed upon many negatives, night after night, a very faint spot always nearly in the same position with respect to the sixth and seventh satellites. It could not be a photographic fault, for it was repeated so often. It could not be a star, for Jupiter and his moons, in their orbit, changed their background of stars every night. At last all doubt was dispelled. This almost invisible dot of the eighteenth magnitude, invisible in the telescope to the human eye, was undoubtedly a new satellite, Jupiter's eighth moon.

After examining the position of this satellite upon different nights, in order to compute the orbit in which it travels round Jupiter, the chief assistant, Mr Cowell, found that it revolves in an orbit outside all the others, highly inclined to the planes of the others, and, most remarkable and unexpected, he made the surprising announcement that it goes round Jupiter in the opposite direction to all the others that were then known.

If this were all that the 30-inch reflector had discovered, Greenwich Observatory would still be proud of it.

IV

The twin telescope on this mounting is the 26-inch refractor. It is largely used to take photographs of stars, for showing their relative positions on the negative. The mode of inserting a plate in the focus should be inspected. The telescope mounted alongside, and used as a finder, or as a guiding telescope controlled by eye, while the large one is taking a photograph, is the old 12-inch, which, in my days at Greenwich, was the largest telescope in the observatory.

If we were asked what is the greatest research to which the 26-inch has been put, the answer would be "the systematic measuring of the distances of stars from us by the ordinary method adopted by surveyors, but with the use of a base whose length may sometimes reach one hundred and eighty-six million miles."

This is the distance between two positions of the earth six months apart, due to her revolution round the sun. If one star of a group that appears on the negative be much nearer to us than the others, photographs taken six months apart exhibit a minute displacement of it with respect to the others. These displacements (called "parallaxes") are measured with great accuracy under a microscope, and already the list of parallaxes published by the present Astronomer Royal forms a notable addition to our knowledge about the stellar universe. Fifty years ago such a catalogue of stellar distances was unattainable, so difficult were the observations by heliometer, which was then the best instrument for the purpose. The invention of the gelatine dry-plate in photography has given the opportunity, and astronomers have seized it. For understanding the structure of the heavens and the movement of the stars, there is no class of facts more urgently required by astronomers than these stellar distances. The good start that has now been made by photography is promising, and already much has been done.

V

Having inspected all the wonders of these twin telescopes, and particularly the superbly ingenious mechanism of the clockwork for driving the telescopes round the polar axis smoothly and regularly,

you will find a host of objects of interest displayed in this great building on visitation day.

You can look at some of the negatives of the great photographic chart of the whole heavens that was completed by Mr Franklin-Adams.

You can see a model, in wire, showing the path of the eighth satellite round Jupiter since its discovery. Jupiter is so far removed from this outer satellite that his controlling power is feeble, whereas the gravitation-attraction by the sun, a thousand times more massive than Jupiter, is a powerful disturbing factor. This is shown on the wire model by the twists and deviations of the wire from a true ellipse, in which figure it would travel if it followed Kepler's law.

Then, on the ground floor, on this day, charts can be seen relating to sun-spots and magnetic storms, all illustrating the latest discoveries about the wonderful, unexplained, eleven-year period of sun-spots, terrestrial magnetism and auroræ.

But the most interesting side-show of all is to-day displayed in the astrographic-room. Here you can see the micrometers in use for measuring the relative positions of stars on the photographic plates, whence we derive the parallaxes and distances of the stars.

And all round the room may be seen the wonderful astronomical photographs that have been secured, both here and abroad, of the sun, of total eclipses, of comets, of star-groups, and those marvellous pictures of nebulæ that have revolutionized our notions about the universe during the present century.

VI

Our steps now naturally turn back to their starting-point, where the instrument most representative of Greenwich Observatory stands on the zero of longitude. This is the transit circle. Its purpose, besides getting true time for correcting the clock error, is to enable the astronomer to define with the utmost accuracy the direction in which any one of the heavenly bodies lies, with respect to all the others.

The work now being done by this instrument, and the work that has been done by it or its predecessors since 1676, for nearly two hundred and fifty years, is the work for which Charles II.

founded Greenwich Observatory, now the premier observatory in the world. This was about the same time that he founded the Royal Society, now the premier scientific body in the world. He had been impressed by learning that the longitude of a ship at sea could become known if the moon's place among the stars could be predicted. He was convinced that the commerce of Britain and the safety of her mercantile marine would gain from the development of this scheme. For this reason he founded Greenwich Observatory.

From that date to now the positions of the moon, planets and stars have been recorded here with more continuity, and generally with greater accuracy, than anywhere else. Hence mathematicians are now able to foretell at any time the position that will be reached by the moon at any time in her monthly track round the earth, among the stars. Thus the moon is like the hour-hand of a great celestial clock, and the circle of stars lying along its track mark the hours in Greenwich mean time. Sailors and explorers carry with them the "Nautical Almanac" containing these predictions. In this way the traveller in distant lands or seas can learn the true Greenwich time at any moment when he can see the moon. He can also find, very easily, by observation, his local time. And the difference between ship's time and Greenwich time gives the sailor his longitude. This makes the traveller independent. He need not then rely upon a chronometer to show the Greenwich time.

Look now at the transit circle ; it is a telescope with trunnions at its middle, like a cannon. These rest upon V-shaped bearings rigidly fixed on the foundations. The trunnions must be level, and must point east and west. The telescope can turn round on its trunnions to any elevation above the horizontal position, to catch any star at the moment when it passes the "meridian," which is an imaginary north and south line in the sky. He can measure on a divided circle the altitude to which the telescope points. He can also record the exact moment when the star passes the meridian wire in the focus of the telescope. These two records suffice to define the direction of the star, as compared with all others.

It would take up too much space here to describe the beautifully accurate details, in construction and use, which render the

observations made with a transit circle as nearly perfect as anything depending upon human workmanship can be. Improvements are constantly being introduced ; but to-day there is only one transit circle in the world that is acknowledged to be superior to the Greenwich one.

It is a matter of pride to us, and especially to us Scotsmen, that the most perfect transit circle in the world is the one designed by our countryman, Sir David Gill, and set up by him at the Royal Observatory at the Cape of Good Hope, and completed in 1901. That splendid Scot was the finest astronomical observer of his age, with a genius for designing instruments and using them so that all errors, known or unknown, should be nearly cancelled out. With unbounded energy he built up the Cape Observatory from rudimentary beginnings, and, after twenty-seven years, left it in 1906, only when he had made it the premier observatory for all purposes in the Southern Hemisphere, and the finest observatory of position in the world.

To indicate the perseverance and skill of David Gill, three researches of his at the Cape should be mentioned.

He took a bar of steel, four metres long, to Paris, and compared it with the standard metre there. He took it to South Africa and measured with it a base-line on the ground. Starting from this base-line about two miles long, he surveyed the country over several degrees of latitude, and so he measured the diameter of our globe.

Using part of this diameter as a base, he extended his survey to get the distance of the sun and the diameter of the earth's orbit.

Using part of this last diameter as a base, he extended his survey to get the distances of a number of stars, all measured in terms of the Paris standard metre.

Any one of these researches might have taken a lifetime. And each required skill of the very highest order. He did them all, to the admiration of the world.

VII

To return to our inspection, there are other three instruments deserving more detailed description than can be bestowed upon

them in this article. There are the Altazimuth, the Astrographic telescope, and Cookson's zenith telescope.

The moon cannot be well observed on the meridian when it is near to the sun. Consequently the observations of the moon used to be defective during that part of her orbit. In order to increase the reputation enjoyed by the Greenwich lunar record, Airy set up an *altazimuth* for getting her position when not on the meridian. It is really a glorified theodolite. The calculations required for deducing, from observations of this kind, the true longitude and latitude of the moon are a little severe. Fifty years ago it used to be narrated that every assistant who up to then had had this duty either committed suicide or died in a lunatic asylum.

The *astrographic telescope* is one of eighteen made, after a congress of astronomers at Paris in 1887, by many countries to enable them to take part in a systematic charting by photography, and cataloguing, of the stars of heaven at this period of the earth's history. It was an ambitious scheme, and has for the most part been carried out with splendid success.

The Greenwich astrographic telescope was dismounted in 1922, and carried out to the antipodes to test the Einstein theory during the total eclipse of the sun. Bad weather prevented its use then. Such are the kinds of disappointment that astronomers learn to bear.

The *Cookson zenith telescope* and its mounting are floated on mercury. So that, even if the instrument be turned about the vertical through one hundred and eighty degrees, the photograph of a star in the zenith still comes on the same part of the photographic plate. It is used for finding, with great exactitude, the direction of the vertical, and the latitude. It has been discovered that, all over the world, the latitude varies from month to month and from year to year. In other words, the axis of the earth about which she rotates moves about in the earth itself. This floating zenith telescope is perhaps the most perfect instrument for measuring the amount of this shift.

It might perhaps be truly said that the most important instrument in the observatory is the sidereal clock, which is corrected by star-observations. Without it, the transit circle itself would lose its value. The clock-room is full of interest to the specialist. So is the wireless-room, where the exact time, as indicated by sidereal

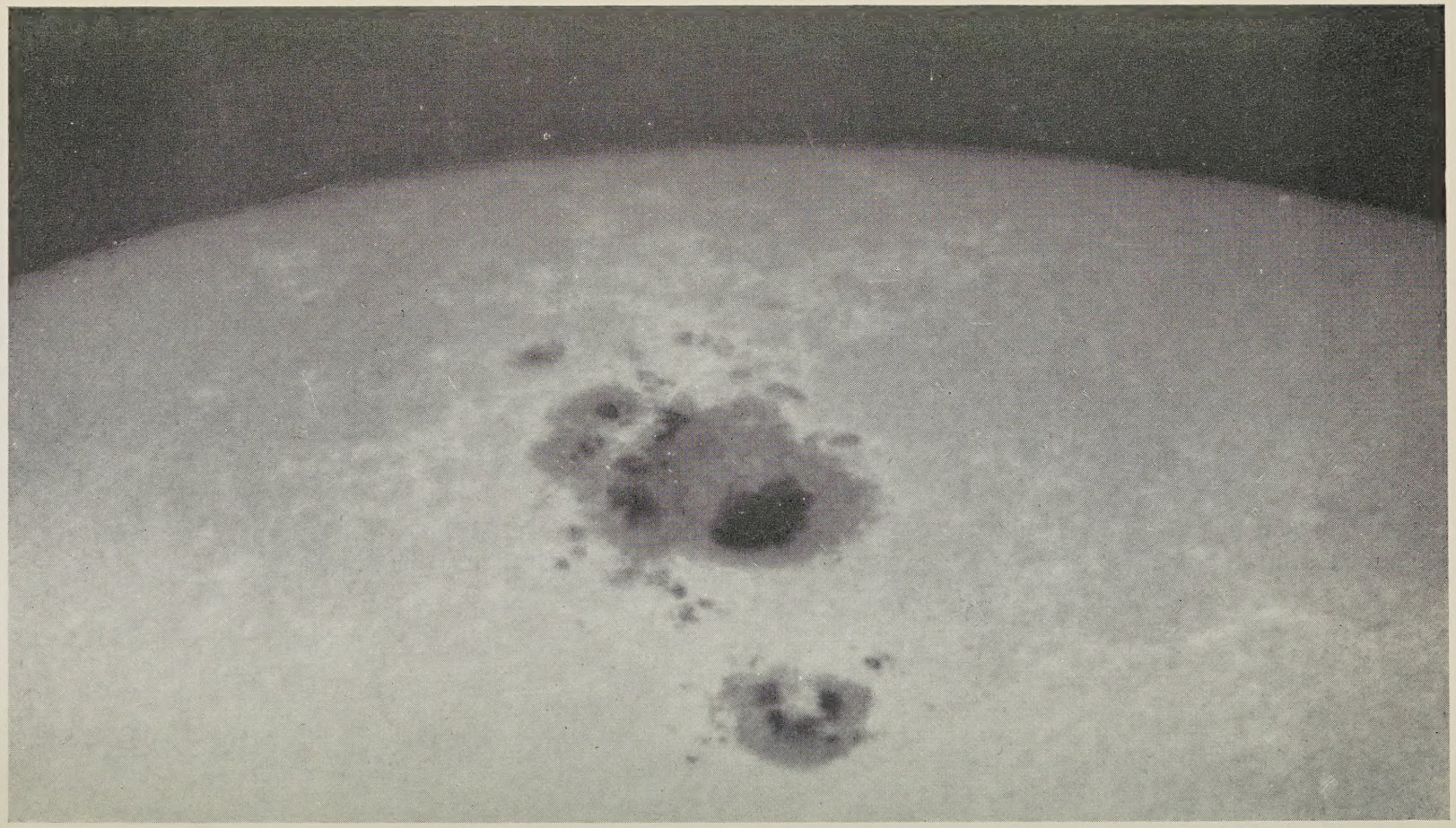

PLATE VI.—GREAT SUNSPOT [*Greenwich Observatory*

Perhaps the largest ever photographed (18th January 1926). Showing Umbra and Penumbra, surrounded by bright Faculæ

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clocks in foreign observatories, is received from Paris or Bordeaux, or elsewhere, and can be compared with the Greenwich clock. But the great attraction lying in these rooms is of so very technical a character as to be unsuitable for these pages. The chronograph is a revolving drum covered with paper, upon which an electric pen makes marks. These are made by electric signals from the sidereal clock, and also from the transit circle when a star is on the meridian wire. This enables the assistant to find the time, true to a small fraction of a second, when the star crossed the meridian.

By this visit to the observatory we have gained some insight into the instruments and processes available to the astronomer, but there is one thing that can be only dimly visualized by a mere inspection. This is the great skill, patience and tenacity that must belong to every astronomer who adds by his discoveries to the glory and fascination of his beloved science.

For without that personal devotion no man can become a real astronomer. There is always something lacking in the man who makes use of the Queen of Sciences for his own advancement, or the quibbler for priority of discovery. The heavens declare the glory of God. The observatory shows the handiwork of man. And further, it shows the almost Godlike humility and perseverance of astronomers who, with incredible precision of measurement and the absolutely accurate reasoning by mathematical processes, go on from truth to truth in the interpretation of the wonders of creation.

CHAPTER VIII

TORNADOES IN THE SUN

I

In the year 1610, for the first time, a telescope was directed to the sun, moon and stars. From that moment a new era of astronomy began. Every day or night that the fortunate possessors of the first telescopes pointed them to the heavenly bodies they made a new discovery. Afterwards every increase in the size of telescopes, or in the perfection of their definition, opened up new fields for exploration. The enthusiastic delight of astronomers, in devoting their lives to their incomparable science, reached a climax in making these discoveries.

Just two hundred and fifty years later, for the first time, spectroscopes were directed to the heavenly bodies to find out what they are made of. From that moment a second new era dawned upon astronomy. Every time that the fortunate possessors of the first spectroscopes pointed them to the celestial objects they made a new discovery. Every improvement in its optical perfection, or in the way of using a spectroscope, opened up new fields of exploration. There are many of us still living who can recall the excitement with which these first revelations were received, and the enthusiastic delight of those astronomers who were devoting their lives to our glorious science, when the marvellous power was given to them of finding out the materials, the chemical elements, from which stars have been made. Everything in our world is made out of less than a hundred chemical elements, and spectroscopes enabled chemists in their laboratories to find which of these elements existed in any substance, by the colour of the light they gave off when heated by a flame or by an electric spark.

Afterwards astronomers found that they could carry on the same process of chemical analysis not only upon specimens in the laboratory but even upon the sun, and upon stars and nebulæ that are billions of miles away. To-day it is a commonplace, but sixty years ago the discovery of this new power put into the hands of astronomers seemed to resemble the discovery of America by

Columbus, in opening out new fields for exploration, and adding to the sum of human knowledge and endeavour.

If a pinch of salt (or sodium) be thrown on the flame of a spirit lamp the flame becomes yellow. If strontium salt be used the flame is red. Other salts give other colours. Or if two wires from a strong electric battery are brought in contact and separated slightly, a coloured arc of light shines. If the wires be iron, copper or zinc the colour of the light differs with each metal.

These are the first steps by which chemists can distinguish materials by the light they emit, when hot enough. But the eye is only a rough guide in thus distinguishing different colours.

When we look at these coloured flames through a glass wedge, or "prism," all of the colours in the flame are spread out into a spectrum, and we see one yellow flame of sodium, three or four flames of strontium, side by side, of different colours. The spectroscope does nothing more than this, only with so great precision that each colour can have its position in the spectrum-scale exactly measured. And each chemical element is found to have its own set of colours, generally very numerous, if powerful optical appliances are used.

When we attach to the eye-end of a telescope the combination of lenses and prisms called a spectroscope, and when we look at the sun, we see its white light drawn out into a long strip of colours side by side, the same colours as those we see in a rainbow, and in the same order. At one end the strip is red ; this merges through orange into yellow, and then through green to blue, indigo and violet. Also we notice numerous dark lines across the solar spectrum, indicating that certain colours are missing, or else much weakened, in the compound white light coming from the sun. The fact is that these colours have been absorbed by chemical elements in the sun's atmosphere. The white light, starting from the denser, but still gaseous, body of the sun, has been deprived of certain colours in the spectrum ; these being absorbed by metallic and other vapours in the less dense and cooler atmosphere above.

The astronomer measures the position, on the spectrum-scale, of these colours in a star's light, and then compares them with the position of spectrum-lines, measured by the chemist in his laboratory, belonging to each metal or other elementary substance.

For example, there are hundreds of bright lines of different colours seen by the chemist in his laboratory in a spectrum of the light emitted by iron atoms when an electric spark passes between two pieces of iron, and these particular lines are not shown by any other metal. These hundreds of lines are all reproduced as dark lines in the solar spectrum, in exactly the same measured places as the chemist had found with iron in his laboratory. In the same manner other chemical substances are found to have their own lines in other positions on the spectrum of the sun, agreeing with positions measured in the laboratory. In this way we learn that iron, and other elements known to us, exist in the sun's atmosphere.

For greater precision the best plan is to photograph the spectrum of sun or star. After this is done, the exact positions of the lines can be measured carefully several times at leisure.

This is one of the greatest marvels resulting from persevering effort in the study of science. It is a great triumph to be able, with a telescope, to bring the sun or the moon a thousand times nearer to us. But how much more wonderful is it to be able to analyse the chemical constitution of the sun, ninety-three million miles away, in the same manner as metals are analysed in our laboratories! And when we think of applying the same process to stars and nebulæ, millions of times more distant than the sun, we are lost in wonderment in contemplating the vastness of the realm for discovery thus opened to the researches of a new generation of astronomers, stimulated by a new sense of power.

Most of the thousands of dark lines crossing the solar spectrum have been identified as belonging to substances found on our globe. Forty or fifty of the terrestrial elements have already been found in the sun. The heavier metals like gold and platinum have not yet been discovered. They may well exist among the lower, highly compressed gases, where the atoms are not free to vibrate in their own specific manner. In that case the crowded atoms all combine in radiating white light with its continuous spectrum of all possible colours.

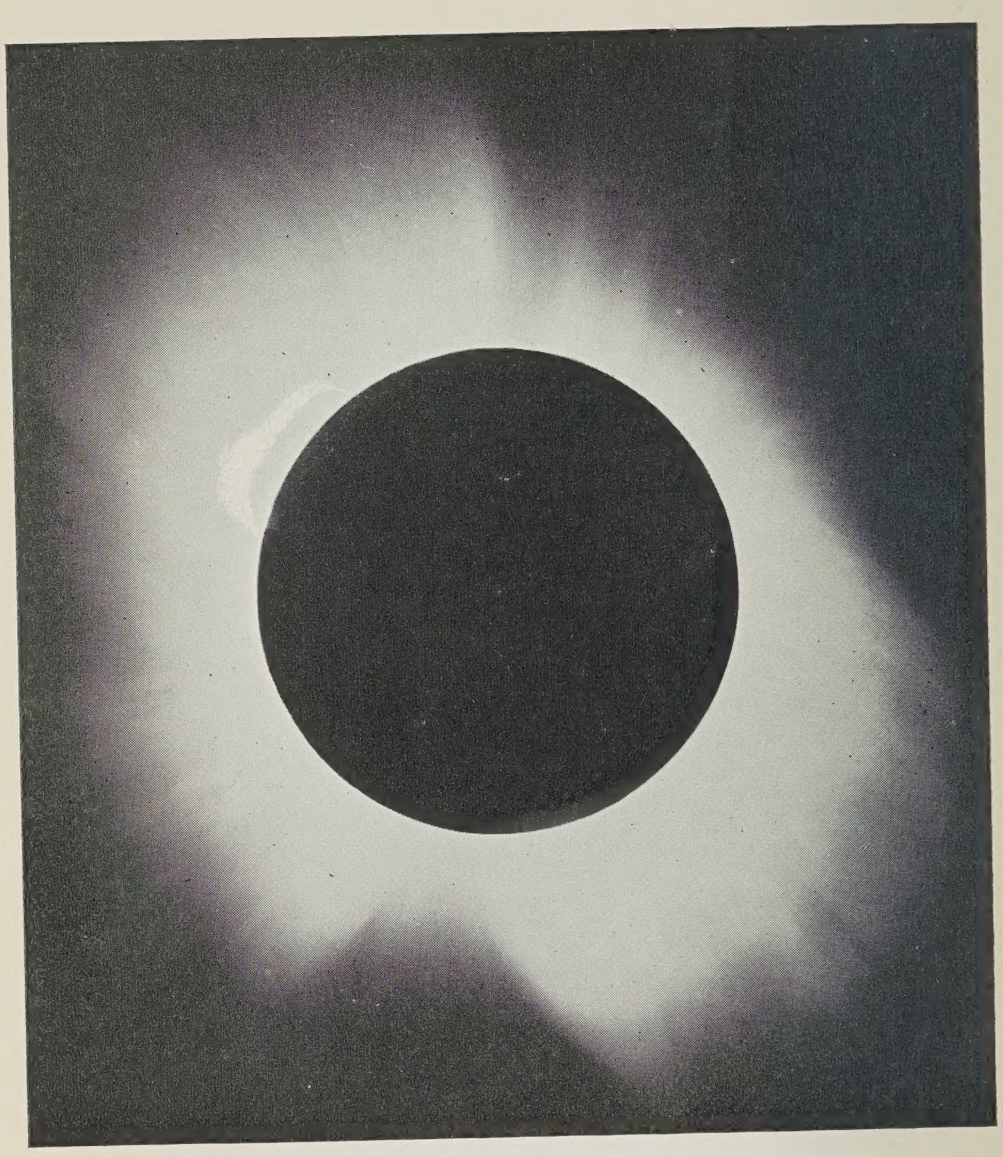

PLATE VII.—TOTAL ECLIPSE IN 1919
Longer exposure to show Corona

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II

The agreement in position of hundreds of dark lines in the solar spectrum with hundreds of bright lines, say, in the spectrum of an electric arc, that are emitted by iron, makes us nearly certain that the solar dark lines and the laboratory bright lines belong to the same material—iron. And so it is with other elements. Fortunately there is a very beautiful way of seeing that these lines of iron, etc., in the sun's atmosphere, though seen dark when the white light of the sun's body shines through the iron vapour, become bright, like the chemist's arc-spectrum, when the sun's white light does not shine through them.

This happens during a total eclipse of the sun, one of the most wonderful and awe-inspiring sights ever presented to man. They occur nearly every year at least once, but are visible only from a limited part of the earth's surface. At present our attention must be directed to one particular feature of total eclipses.

As the moon advances, like a round, opaque, black screen, over the sun's bright disc, just before it completely hides the sun, there is a moment when only a faint line of the sun's edge is left shining. It is the last visible bit of the sun's surface to shine with white light. And this light, up to that moment, shines through the less compressed gases of what may be spoken of as the sun's atmosphere. So we still can see their dark lines in the spectrum. A moment later and all the white light at the edge of the sun is eclipsed, before the black moon has reached, and cut off from our sight, the upper atmosphere. At that moment, looking through our prism, we see all the dark lines flash out for less than five seconds, reversed, and shining brightly each with its own colour, the same as the laboratory spectrum of *bright* lines, when an electric spark passes between two metal points.

In this simple observation we have a proof that the dark lines seen in the spectrum of the sun or the stars are lines of absorption due to gaseous atoms that cut off certain colours, the same colours as these atoms emit when seen with no background of continuous spectrum given by white light. The flash spectrum in a total eclipse has been often photographed. It was photographed for the first time in 1896 (Plate XI.).

A total solar eclipse is so extraordinary a sight in all its aspects that an astronomer has to exercise great control over his emotions to enable him to concentrate attention on the observations for which the opportunity of totality lasts, at most a few minutes.

At that moment, when the whole of the sun's white surface is blocked out by the moon, the world in darkness, and stars in the sky, we see irregular "red prominences," deep red, like clouds, or volcanic outbursts that have shot up through the sun's atmosphere. They rise at times to enormous heights beyond the circular edge of the black moon. They are of many shapes, some like flames, some forming arches, others cloudlike.

And outside of all is a halo of greenish colour, which suggests an outer atmosphere. But this "Corona," as it is called, is not structureless like an atmosphere. Nor has it any sharp boundary. The brightness diminishes rapidly outwards, and has a structure of long streaks or filaments that extend outwards from the moon's edge in broad curved sweeps. The shape is different in each total eclipse (Plate VII.).

The "Prominences" and the "Corona" seen in total eclipses have received much attention from astronomers. The spectroscope tells us that the red prominences are made of shining gas, mostly hydrogen, the lightest gas known to us. Now, by looking through a powerful spectroscope and concentrating attention on one of the hydrogen bright lines, the red prominences at the edge of the sun can be distinctly seen and their shapes examined. So we are enabled, even when there is no eclipse, to watch the rapidly changing shapes assumed by the outbursts of gas through the sun's atmosphere from hour to hour. These have on occasion been seen to shoot up to a height above the sun's surface greater than the whole diameter of the sun (Plate VIII.).

More than forty years ago a certain bright yellow line was found in the red prominences which belonged to some substance then unknown upon the earth. To this substance was given the name "Helium," from the Greek word that means "the sun."

There is also a line in the spectrum of the corona which is due to an element not known to us as existing upon the earth, and to it the name "Coronium" has been given. Helium and coronium were for a long time believed to be two substances in the sun that

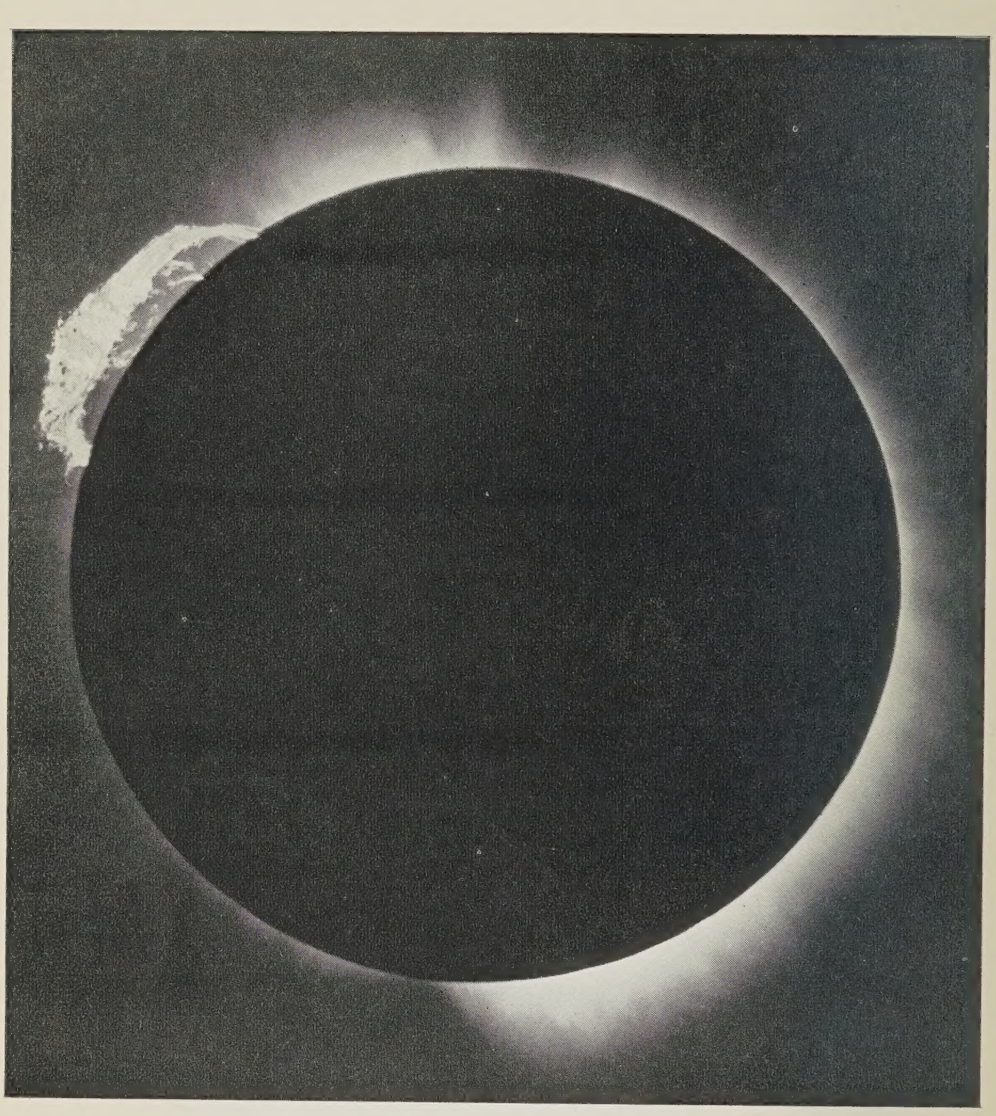

PLATE VIII.—TOTAL ECLIPSE IN 1919
Shorter exposure to show Red Prominence

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do not exist upon the earth. Coronium has not yet been found on our planet, but helium was discovered by Ramsay, the great Scottish chemist, in 1895. He analysed, with a spectroscope, certain bubbles of gas that exist in the natural crystals called "cleveite" and, to his astonishment and delight, he found its principal spectrum line to be identical with the helium line in the spectrum of solar prominences.

For many years this new element helium was a rarity. Its density is less than any known substance, except hydrogen, and it was collected and examined for the scientific importance it was found to possess in regard to the properties of chemical elements.

Later in our history new sources of helium have been discovered in some of the mineral oils, and its production from this source is now abundant. During the Great War people recognized its value, if it could be obtained in sufficient quantities, for replacing hydrogen to fill balloons. Its lightness made it suitable for the purpose, and its non-inflammability gave it a superiority over hydrogen. This led to the extraction of helium from mineral oil on a large scale by the Americans. At the date of the Armistice they had ready for shipment to France one hundred and forty-seven thousand cubic feet of helium gas, collected from oil-wells of Texas and Oklahoma, at a cost of only fivepence per cubic foot. And, only a few years previously, this gas could not be found anywhere except in the sun!

Helium is observed only at the sun's edge, not on its general surface. There are many stars in which helium is the material most easily detected.

III

Although the unique character of the sun's appendages, as seen during a total eclipse, is so weird and startling as to strike the ignorant with terror, and the astronomer with feverish anxiety to attain his results within the short time of totality, yet, even at other times, the sun's surface gives us much to think about.

Often in a fog, or when the red sun is setting, so that, without inconvenience, we can look at it directly, one or more black spots may be seen upon the sun. Some years give more opportunities than others for seeing these spots. Then, with patience and good eyesight, no telescope being used, but only a deep-coloured or

smoked piece of glass, there is a fair chance of seeing them occasionally, and of noting their movements over the sun's surface from day to day. In the year 1919 certain observers stated that, on forty-six days out of every hundred when the sun shone, they saw spots with the naked eye.

Every eleven years there is a maximum in the number of sun-spots, and in their size. Now, it has been noticed that fluctuations occur in the magnetic condition of our globe that directs a compass-needle to the north. And occasionally there are violent fluctuations in this directive force. We call them "magnetic storms." The frequency and the violence of these magnetic storms have also a period of eleven years, and the years of maximum always agree with the years of maximum of sun-spots. Also, it has been noticed often that the most violent magnetic storms are associated with great activity in some large sun-spots near the centre of the solar disc. And again, the frequency of auroral displays follows the eleven-year period, and reaches its maximum with the sun-spots.

These facts add increased interest to the study of sun-spots. If terrestrial phenomena are affected by the conditions that give rise to sun-spots, we naturally wish to find out all that we can about these spots.

The easiest way to see the spots is to point a telescope to the sun and hold a sheet of paper a foot or two from the eye-end, so that the sun's light, coming through the telescope, shines on the paper. By drawing out the eyepiece a little, the sun's edge can be made to appear sharp and clear on the paper. Then, if there be spots at the time, they will be seen very clearly on the paper. This is a delightful way for observing spots, and even for drawing their shape and position, if a small telescope be available on a firm stand. Otherwise, if you look directly through the telescope, it must be provided with a dark-coloured glass to prevent a serious injury to the eye.

Either of these methods, especially in a year of sun-spot maximum, enables anyone to find out a great deal for himself. The spots will be seen to move from day to day across the face of the sun. They pass from the east edge to the west edge in a fortnight, and occasionally reappear at the east edge in another fortnight. So the sun is found to rotate in about twenty-five days near the Equator, and twenty-eight days in higher latitudes. This differential rotation

would not be possible if the sun with its spots were a solid globe. It is really gaseous, under tremendous compression due to gravity, except at the outside layers. Still, there must be enormous friction between the layers of gas at different latitudes that have different velocities of rotation. And no one has ever been able to explain how this difference of velocity is maintained, or whence the energy expended in friction is renewed.

The spots will be seen to have no permanence. Often they begin as a small spot that grows ; or a whole group of spots may gradually form in the same place. Some last only a few days, others for one or two revolutions of the sun. The longest endurance hitherto observed for one spot was eighteen months. They are seldom found near the Equator, never at the poles.

The spots are not uniformly dark. Although differences cannot be detected with the naked eye, yet even a small telescope shows us that generally there is a very dark "umbra" surrounded by a less dark "penumbra." At times one penumbra includes many umbræ. There is usually a "facula," or patch of light, brighter than the general surface of the sun, round and near the penumbra, or following it (Plate VI.).

Many spots are seen to be hollows on the sun's surface, shaped like a saucer, the umbra being the bottom, and the penumbra forming the sloping sides. When such a spot is close to the edge of the sun the saucer is tilted, and the part of the penumbra farthest from the sun's edge cannot be seen on account of the sloping sides of the saucer-edge. There is much enjoyment for a keen mind in drawing on paper these changes as seen from day to day.

For a deeper study of spots, recourse may be had to the daily photographs that are taken at many observatories ; or some of the books that have been produced, with sun-pictures continued through many years, may be more accessible for showing the changing appearance of the spotted sun.

IV

There are occasions when, in the pursuit of our glorious science, wonder and admiration are transferred from the heavenly bodies themselves and their origin to the ingenuity of man in his efforts

to delve further into the mysteries of creation. Man has to draw upon his knowledge, whether it be positive or only probable—knowledge which may be practical, theoretical, or even no more than hypothetical. The finest skill of the mechanic and the optician is called into his service. The wave theory of light, the chemical theory of atoms and physical hypotheses as to the constitution of these atoms and their electrons, besides a number of speculative views, are for the moment adopted as more or less probable statements of the existing conditions that must be studied. These "working-hypotheses" have indicated directions in which research may proceed with the best expectation of positive results. Guided thus by such indications, our knowledge of the constitution of the heavenly bodies has of late years taken enormous strides in directions which, only a few years ago, would have seemed to be beyond all possibility of investigation.

In no direction has this been more apparent than in new applications that are continually being discovered for that marvellous instrument of research, the spectroscope. Its astronomical use and purpose was originally to discover what the sun and the stars are made of. Then it was found that a shift of the spectrum lines supplied by a star told us the velocity with which the star is moving towards or from us. Innumerable applications of this principle have led to discoveries in all departments of astronomy. Next, from laboratory experiments we learned that the spectrum lines of a gas are widened when the gas is compressed more densely. And by measurements of relative intensity of light in different parts of the spectrum we have gained knowledge about the temperature existing on the surface of different stars.

Moreover, it has been found that when the atoms of a gas are subject to magnetic forces, their spectrum lines are split up into doublets or triplets, and the light is what is called "polarized." These magnetic effects have actually been detected in the sun. And now, every day when the sun shines, the strength of this magnetism is being measured and plotted upon the different parts of the sun's surface. This is a matter for great surprise, because magnetic materials all lose their magnetism at temperatures far below that of the sun. But an electric current in a ring of wire acts just like a magnet. Also an electrically charged bead revolving

in a ring acts just like a ring of electric current, and therefore like a magnet. So the magnetism found upon the sun is supposed to be the result of electrically charged "electrons" in the atoms that are carried by whirlwinds round ring-orbits.

This sounds very hypothetical. But concerning the existence of magnetic fields on the sun's surface there is little, if any, room for doubt. Also, the actual positions of the two magnetic poles of the sun have been found. As on our earth, these magnetic poles are not very far from the poles of the sun's axis of rotation. The period of rotation of these poles round the sun is thirty days: a longer time than the spots, which are all nearer to the quick-moving equator, take to go round the sun.

This new application of the spectroscope is so wonderful that doubtless many readers will be tempted to make a study of another new instrument, the spectroheliograph, and of what has already been accomplished. Here it is possible only to indicate briefly how the spectroheliograph can enable us to observe the structure of the sun's surface, when it is free from spots, and almost structureless, as seen through a telescope.

The instrument called a spectroheliograph was invented to enable us to take a photograph of the sun, *all in the one colour*, that is allowed to pass through a slit in front of our camera. Any colour may be chosen, such as one of the colours given off by hydrogen or calcium. All we have to do is to place the slit at a hydrogen dark line, or a calcium dark line, on the sun's spectrum. These lines are dark compared with neighbouring colours, but there is plenty of light from them to give a good photograph. The spectroheliograph moves over the sun's image in the telescope, and the camera produces a complete photograph of the sun in one colour.

In this way a calcium photograph of the sun shows clouds of calcium in different parts of the sun's surface vastly greater in area than the sun-spots. And a hydrogen photograph shows clouds of hydrogen quite different from the calcium ones.

Yet another marvellous result has been attained. The spectrum-lines of the chemical elements are changed, either in width or intensity, or both, when the gas is more or less compressed, by being deep down or high up in the sun's atmosphere. And it is now possible to get calcium photographs quite different in appearance

by choosing a position of the slit suitable for great or for small atmospheric pressures. Thus at any hour one photograph can be taken of the calcium clouds at low altitudes in the solar atmosphere, and another at higher altitudes (Plate IX.).

In this way of working, progress has been rapid. Since 1908 it has been possible to photograph certain hydrogen clouds that are high up in the solar atmosphere. It is from these photographs that have been attained the most surprising results, shedding a new light upon our knowledge of the origin of sun-spots.

It had been expected that the new exploration would have disclosed currents in the sun's atmosphere analogous to those familiar to us in terrestrial meteorology. The calcium "flocculi" (as they are called) revealed the existence of no such currents; and it was not until 1908 that any were discovered, when hydrogen in the upper regions could be photographed, owing to the production of a photographic plate sensitive to red.

These hydrogen flocculi are located over the sun-spots, and their forms proved that *all sun-spots are vortical in nature, and are probably analogous to terrestrial cyclones or tornadoes.* Most of the solar vortices indicate clockwise rotation in the Southern Hemisphere, counter-clockwise in the Northern, as in the case of terrestrial cyclones; but there are many exceptions to this rule.

Many of these hydrogen photographs of solar tornadoes above the sun-spots have been published. They are of surprising interest. It happens that a certain discontinuity in the hydrogen vapour enables us actually to see in black and white the whirlwind form. Spiral arms, more or less complete, are seen radiating out from the central, black, circular spot. The general drift of the spiral arms is clearly in one direction of rotation. And if there be a pair of whirlwind-spots, as is common, the picture of these, rotating in opposite directions, is most suggestive.

But this is not all. After this great discovery had been made, George Hale, at Mount Wilson Observatory, followed it up by the astounding discovery, already referred to, of the known indications of a magnetic field within these vortices, or tornadoes.

Since the year of these discoveries, 1908, continuous observations have been made upon the magnetic poles near sun-spots, on the general magnetism of the sun, and on cyclones that form the spots.

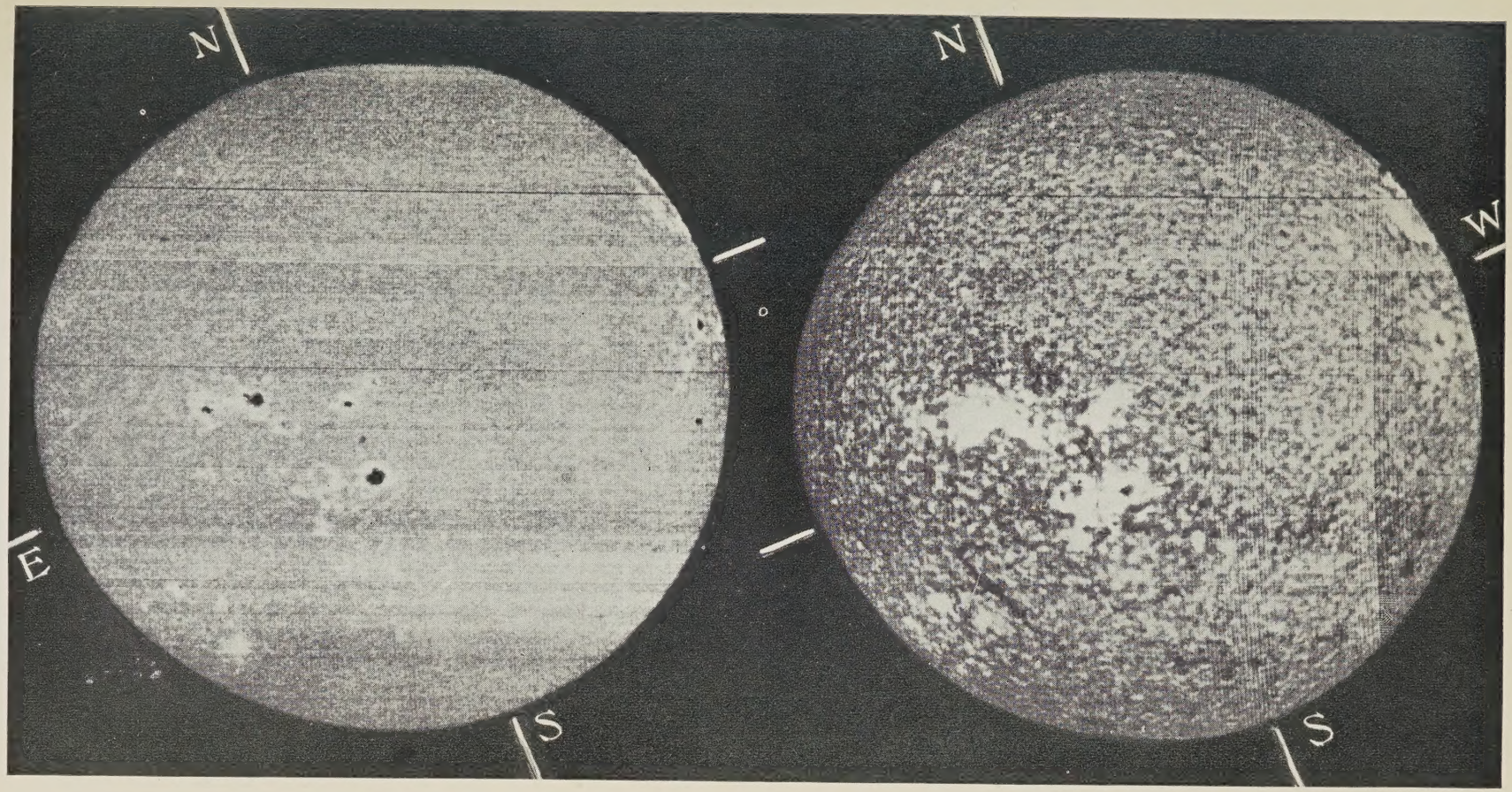

PLATE IX.—PHOTOGRAPHS OF SUN'S ATMOSPHERE AT TWO DIFFERENT LEVELS [*Meudon Observatory*

Each photograph is in a single colour, K_1 and K_3 of Calcium

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A sun-spot is often double, with opposite directions of rotation and with opposite magnetic polarity in the two vortices. One of the pair may be the first to disappear, before the other one, and in such cases Hale has found the magnetic polarity to continue. He has gone further, and has been able to locate the second spot of a pair, *before it is visible in the telescope*, by the magnetic field ; and his researches are now extended to the detection of invisible sun-spots. He also is able to confirm the tornado-character in another way. A large cloud of hydrogen may hang for several days upon the edge of one of these vortices, and he has seen these suddenly sucked into the spot's whirlpool with a velocity that has been measured as sixty miles a second.

Vortices, whirlwinds and whirlpools are the inevitable result of turbulent motion in the air or water when two neighbouring parts have different velocities. When a ship is steaming fast, on our looking down the ship's side at its junction with the sea the speed of the water touching the ship's side gives a turbulent motion, shown by whirls or cyclones. Now the sun's surface at any latitude rotates in a shorter time than the surface at a higher latitude. This tends to set up vortices in the Northern and Southern Hemispheres in opposite directions, as Hale found.

It has been suggested that sun-spots occur only when this differential velocity is large enough to give rise to turbulent motion, and that this varies periodically, and so gives rise to sun-spot periods of eleven years. There is much evidence to support this view, but, at present, it is only a helpful suggestion.

Since the sun is one of the stars whose proximity enables us to study it minutely, all of these solar researches give to us a supreme delight, in that they help us to interpret better the stellar spectra, and so to learn more and more about the constitution of all the stars above. All that we learn about the irregular and periodic activities of the sun may be taken to prevail in any yellow star like Pollux. Thus are some of our friends, the stars, brought nearer to us in new ways. We may almost speak of our cousins, the yellow stars. The marvellous prominences, corona, spots and tornadoes of the sun have, in all probability, their counterpart in the stars above.

A study of the facts about the sun, our nearest star, disclosed to

us by the closer survey with telescope and spectroscope, enables us to picture in our minds some idea of what conditions we should discover in the stars could we survey them from a similar distance.

We find that the sun's diameter is about ten times that of Jupiter, and a hundred and ten times that of the earth. Its mean density is only a quarter of the earth's, and its enormous size would increase the weight of anything twenty-sevenfold if it could be taken from the earth's to the sun's surface.

The composition of the sun, at a temperature of 6000° C., is gaseous, under so enormous a compression as to emit white light instead of the individual colours emitted by the gaseous or vaporized materials, chiefly hydrogen and metals. The constituents of the upper atmosphere, not so compressed, exhibit in a spectroscope the dark lines characteristic of the constituent vapours.

The equatorial atmosphere rotates quicker than that at higher latitudes, and the whole atmosphere is in turbulent and eruptive motion. This gives rise to sun-spot tornadoes, and outbursts of hydrogen and helium to beyond the visible limits of the atmosphere. And the whole mass is surrounded by luminous sprays and filaments shown as the "corona" in a total solar eclipse.

When we gaze at the stars that look like points of light, it is good to know that this is the kind of condition we should discover could we approach them closely.

Some stars may be larger or smaller than the sun, and may be hotter or cooler. We already know that the diameters of some exceed the whole diameter of the earth's orbit, and their density is very feeble. But, generally, astronomers have not found, for certain, many stars containing very much more, or very much less, material than the sun, though it may be more or less concentrated.

These round globes of condensed vapours, which we call stars, are probably all rotating, boiling and bursting into eruption, with cyclones of gigantic proportions in their atmospheres. This is something to know about the stars. Some day we may learn more about their sun-spot periods, their magnetic condition, their rotation periods in different latitudes, their temperatures and densities. The more we learn from scientific observation and experiment the wider and more extensive seems to be the unknown field beyond.

CHAPTER IX

SURPRISE VISITORS AMONG THE STARS

I

THE certainty and immutability of the laws that govern the movements of stars and planets have something to do with the satisfaction felt by the ordinary man who watches them. But the human mind is not content with monotony ; so it happens that when, at rare intervals, an unexpected guest among the stars swims into his ken, the " watcher of the skies " welcomes the intrusion with unbounded pleasure.

There are three, and only three, kinds of unexpected starry visitors that may suddenly appear to such a watcher—at any date, without warning. Minor exhibitions are not infrequent, but it is very seldom that they reach the splendour with which all three types surprised and delighted both astronomers and the public some sixty years ago. These welcome but unusual visitors were certain exceptionally fine examples of comets, meteor-showers and new stars ; and the years 1858 and 1866 have ever remained as landmarks to a passing generation of astronomers.

In the year 1858 we saw Donati's comet, with a glowing nucleus and a huge curved spreading tail of light, stretching to a length of fifty million miles. Its head moved visibly among the stars from week to week, and the whole breadth of its tail was seen to pass Arcturus in two hours. This comet had never been seen before, and its brilliant aspect has perhaps never been excelled. It will never be seen again, and down to this day we have not seen its equal. Yet its rival might be found in the sky to-morrow.

In the year 1866 we witnessed the most superb shower of shooting-stars, or meteors, ever seen in the memory of man. During three hours, hundreds of stars every minute, many of them brighter even than Sirius, swiftly swept in a few seconds, from the east, across the sky, leaving broad luminous trains. Since then we have never seen so magnificent an example of a meteor-shower. And yet its rival might be witnessed to-morrow.

In 1866, again, a great bright new star attaining for some days the second magnitude shone for some months in Corona Borealis.

Nothing like it had been seen for two centuries. The surprise and the wonder it excited were beyond description. Since then, as it happened, in 1901 and in 1918, new stars of even greater brilliance have startled the watchers of the skies. And their rival might burst forth to-morrow.

Although comets, meteor-showers and new, or temporary, stars seem to have little in common, yet in 1866 astronomers discovered that comets and meteors do really belong to the same class ; and a theory of " new stars " has been accepted by many astronomers, which was suggested by the luminescence of meteors. Thus the three kinds of surprise visitors that alone appear among the stars may well be considered briefly in a single chapter.

II

Comets.—Although the magnificence of a comet like that discovered by Donati in 1858 may hardly be expected once or twice in a century, yet we do, not infrequently, have visits from very remarkable comets. Most people can remember that in January 1910, while everyone was looking forward to seeing Halley's comet, already foretold, there suddenly appeared in the evening sky another and totally unexpected comet, so bright as to acquire the name of " the daylight comet," because it could be seen in the daylight. Immediately after sunset it used to shine with a bright head, and a long straight tail pointing upwards, away from the place where the sun had just set. And in this respect it behaved as comets with tails invariably do. The tail always points away from the sun. This remarkable fact leads us to the conclusion that the sun, for some reason, is obliged to repel some part of the atmosphere surrounding the head or the body of the comet.

Comets vary much. Sometimes they have no tail and only a nebulous nucleus. Others have many tails. These start from the comet's head in a line away from the sun ; and then, as the comet itself sweeps round the sun, the ends of the tails are left behind, to a greater or less degree, and so the separate tails are more or less curved. The normal comet, seen in a telescope, has a bright head or nucleus, surrounded by an envelope or atmosphere apparently projected from the nucleus *towards* the sun. Then the repulsive

[*After Guillemin*

PLATE X.—DONATI'S COMET, 1858

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force seems to drive it back in a stream, starting directly away from the sun, in a line that is curved in the plane of the comet's motion. The spectroscope tells us that much of its light is reflected sunlight, but the head is partly self-luminous from carbon and metallic vapours. Variations from the normal type are numerous, and should be studied in special comet-books containing drawings or photographs. Glaisher's *World of Comets* (London, 1877), translated from Guillemin's book, is full of interest (Plate X.).

It may be said that, for centuries, the most inexplicable phenomenon in the whole of astronomy was this repulsion by the sun of a part of the comet's material. We all know that, by Newton's law of gravitation, the body of the comet is not repelled but is attracted by the sun ; and so it is guided and directed in its course through the solar system. Why, then, should the sun have a power to repel the tail while it attracts the nucleus ? The astronomer appeals to the natural philosopher, who experiments in his laboratory upon the forces of nature like heat, electricity, light, magnetism, and so on.

The favourite suggestion to-day is founded upon the undulatory theory of light, according to which the atoms of which the sun or a star is composed are vibrating, and transmit waves outwards through an æther that fills all space, the waves being absorbed, more or less, by any material they strike. Now, it has been proved mathematically, and as some claim experimentally, that if the undulatory theory be true, then very small separate particles like the atoms in a comet's atmosphere would be repelled by the sun's light, in opposition to the attraction due to the sun's mass. The principle is a perfectly sound deduction. Multiple tails are supposed to be explained by the greater velocity of the lightest atoms (hydrogen). Thus the hydrogen tail is straighter and less curved than the carbon tail.

III

Although members of the solar system generally, by their strict obedience to the law of gravitation, seem to be a contrast to erratic comets, yet there is no class of bodies in the heavens that has done more than comets have done to establish the universality of that law. Sir Isaac Newton's discovery of gravitation was related to

the solar system and elliptic orbits (a special kind of oval). But his theory showed that there are other curves which the sun might compel the wandering orbs to pursue, provided their velocity were large enough. If a comet, travelling from interstellar space, were to come within the sun's attraction, the sun would increase its velocity and deflect its path until that path would be perpendicular to the sun's attraction. Thereafter the solar attraction would diminish the comet's velocity as the comet receded, and it would deflect the comet's path less and less, until the comet would return to interstellar space with exactly the speed it had at first. Such curves are called parabolas and hyperbolas. And Newton found that all the comets of which he possessed observations of position seemed to be really travelling in parabolas. When far away they are invisible, not only by reason of their distance from us, but because of their distance from the source of light, the sun, that illuminates them.

An ellipse may be so elongated as at its ends to resemble a parabola. The observations used by Newton for cometary positions were hardly exact enough to detect the difference. It was not Newton, but his friend and helper Halley, Astronomer Royal, who discovered that the comet of 1682 was travelling in an ellipse, a very long oval, with one end encircling the sun, the other end away beyond the exterior, and then unknown, planet, Neptune. Thus Halley discovered a new member of the solar system and a new type of member.

Halley's comet returns to visibility, near the sun, every seventy-five years, and its returns have been identified for thousands of years in Chinese and other records. We now recognize Halley's as one of a whole family of brilliant comets having periods of about seventy-five years, and reaching out a little beyond Neptune. There is another and larger family of rather insignificant comets, whose periods are six to eight years, in far less elongated orbits, apparently belonging to Jupiter, as the Halley family do to Neptune.

Each expected return of Halley's comet in the last two hundred years has roused a contest among mathematicians to compute with the greatest accuracy the time when it will next reach its closest approach to the sun. The attraction by each of the planets, sometimes hastening, sometimes retarding, the comet in its voyage, is

computed from day to day for the whole period during which, invisible to us, it is pursuing its course. When Halley's comet returned in 1910, it very nearly conformed to the extremely exact time-table published by the Greenwich astronomers, Cowell and Crommelin. For although, after a journey of seventy-five years, it was late, yet it was late only by two and three-quarter days. And such was the confidence of the mathematicians in their calculations that they asserted positively that though errors might account for the fraction of a day, yet the remaining two days must be due to the attraction by some matter (perhaps a planet) not known to astronomers.

This gives rise to what may be a fantastic suggestion, a hope that comets, when they leave our range of sight, may often be used as messengers to pick up information about distant members of the solar system, and to deliver this information on their next return, in the way that Halley's comet did to the Greenwich astronomers.

Some comets, then, belong to the solar system, and return. But most of them come from interstellar space, and after a short visit go back there for ever. They seem to consist of matter in the form of powder or gravel, and gas. Since all of these particles cannot be in the same place, they travel in different orbits, and probably collide when nearest to the sun. The result is doubtless to distribute streams of particles along their average orbit; and this has been found to be true from a study of meteor-showers.

IV

Meteors.—It is impossible to write a description that would do justice to the great shower of meteors, or shooting-stars, which we saw in this country in 1866, from 11 P.M. on 13th November till 2 A.M. on 14th November. The display was not unexpected, but it began in a startling manner, suddenly, like a concentrated discharge of rockets from a point on the eastern horizon, at the moment when Regulus and the sickle-shaped curve of stars called Leo, the Lion, were rising out of the sea. In five minutes the performance was in full swing, great bright stars all starting from near Leo, all radiating from a point in the middle of the sickle, all shooting over our heads, or away to the right and left of us, all travelling like

orange-coloured lights for two or three seconds and dying out, leaving only a long, straight, luminous trail, broadened in the middle, with which they had in their flight painted the vault of heaven. These trails generally lasted for a few seconds, but sometimes for many minutes, curling up and drifting in serpentine forms, as light clouds are drifted by the breeze. Some of the stars were seen to burst in their flight. Every few minutes a shout would come from a friend, and, turning round, we would see a flight of several together, pear-shaped, bright as Venus until they were burnt out. Then the lanceolated phosphorescent trails, pointed at the ends, grew broader, and were watched in their changing forms until they, too, faded away.

Every individual, astronomer or layman, after having beheld this overwhelming display during several hours, had, inevitably, a feeling that never before in the history of the world had anything so astounding been witnessed by the inhabitants of the world. But from all accounts the display a year later, as seen in America, was equally imposing.

The radiating of all the lines of flight from a point in Leo was clearly an effect of perspective, just as when one stands in a long, straight street of uniform houses the lines of house-tops, of roof-edges, of windows and pavements, which are really all parallel, seem to diverge or radiate from a single distant point on the horizon.

The height of meteors in the atmosphere above the surface of the ground has been measured by the ordinary method used by surveyors for getting the height of a distant mountain. Their altitude generally lies between thirty and a hundred miles. The meteors themselves, consisting of small bits of metal or stone, strike the rarefied atmosphere at those altitudes with velocities commonly ranging from twenty to forty miles a second. The friction of the air retards their motion, and the motion of the mass is converted into the molecular motion which constitutes heat, and the temperature rises to incandescence. There is not the slightest doubt that this conversion of visible motion into heat is the cause of a meteor's luminosity. Particles are torn by abrasion, pulverized and melted by friction with the air, and leave a luminous trail in the meteor's wake.

V

The shower of 1866 was not altogether unexpected, for in 1833 and 1799 the November meteors radiating from Leo had attracted great attention in other parts of the world, whence they could be seen. Records of their periodical visits had been traced back in old records, almost every thirty-three years, to A.D. 902. And astronomers noted the fact that if a great cluster of fine gravelly matter were revolving round the sun in an orbit slightly inclined to the earth's plane of motion (the ecliptic), and cutting it in November, the phenomena of the meteor-shower would follow as a natural consequence. Moreover, if the period of revolution were about eleven days more, or less, than a year, a shower would occur every thirty-three years. Or again, if the period were thirty-three years, the same thing would happen. In this last case it was clear that, in the interval between showers, the cluster of meteoric matter must travel out to a great distance in the solar system, near to Neptune, and back.

In 1866, while the whole world was taking an interest in the remarkable meteor-shower which had just been seen, astronomers made a wonderful discovery about a comet seen during the previous year. In fact, they found that it had a period of just thirty-three years, and was travelling in an orbit cutting that of the earth in November in a direction pointing from the very spot in the constellation Leo whence the meteors were seen to radiate. It seemed certain that if the meteors travelled in the larger orbit, and not in a period of about a year, then the meteoric cluster is an appendage of the comet, detached from it, and travelling in a long, narrow stream which the earth crossed in three or four hours.

Finally, Professor J. C. Adams, discoverer by calculation of the unknown planet Neptune, determined to settle for ever the question as to which of the three orbits belonged to the meteors. He undertook a more laborious calculation even than his Neptune research, so laborious that it seriously affected his health. The object was to calculate any gradual change in the orbit that might be produced by the attractions of gravitation exerted by the masses of Jupiter and other planets. His result was that, with a thirty-three-year period, the planetary attractions would twist the plane of the orbit

so as to retard the point where it meets the earth's orbit by eight hours in each revolution, or one day per century. Also, that no such retardation would affect the other two orbits. Now this is exactly what was found to be the case from old records going back to A.D. 902 : the meteor-shower had always been delayed by one day per century. Thus Adams established with absolute certainty the orbit of the November meteors, agreeing exactly with the orbit of a comet. That is the history of the great discovery of identity between comets and meteors. Further identifications of meteoric with cometic orbits have been established beyond a doubt, and a still larger number with a high degree of probability.

When a cluster of meteors is dense enough to constitute a visible comet, on reaching *perihelion* (or nearest point of the orbit to the sun) collisions and tidal frictions must take place between the particles. This gives rise to high temperature, in addition to heat then derived from the sun. Thus at perihelion we might expect a comet's nucleus to shine not only by reflected sunlight, but also by incandescence due to its high temperature. And this is what the spectroscope tells us is truly the case.

The only really great meteor-shower seen in this country since 1866 was one which was a splendid confirmation of their cometic origin. Biela's comet, a small one of six years' period, used to be observed at each return to perihelion. In 1846 the turmoil of its parts, already mentioned as occurring at perihelion, broke the comet up into two pieces, which sailed away independently. On the occasion of two subsequent returns the parts were again seen. They were then lost for ever. Their orbit happened to cut that of the earth at her position on the 27th November. And on that date, in 1872, we witnessed a superb meteor-shower, with its radiant point in the direction in which the comet would have been moving.

VI

When, as sometimes happens, a meteor is too large to be totally consumed in the air, it may fall upon the earth as an *aerolite* or *meteorite*. These have been seen to fall, and have been found, sunk a foot or two in the ground, at a scorching heat, with the surface molten. On such occasions we pick up direct messages from the far

interstellar spaces where comets are born. We are then privileged to handle bits of matter that may once have been travelling in the regions where Sirius or Arcturus is now wandering, and we are able to examine and analyse them in our laboratories, and to see the kind of material that exists in some of those distant regions of space.

Here it will suffice to say that there are, broadly speaking, two classes of aerolites—namely, "stone" and "iron." The "stones" are composed largely of silicates, and very commonly they have a structure called "chondritic," utterly unknown among terrestrial substances. The "irons" contain nickel also, and many have carbon, not only in the form of graphite, but also diamonds. Some are very pure iron, with less than two per cent. of nickel. It seems quite probable that Mexicans, Canadian Indians, Siberians, Senegalese and Egyptians manufactured implements out of meteoric iron before they knew the art of smelting. Nordenskiöld discovered in Greenland numerous masses of this kind, nearly pure iron, up to twenty tons in weight, but doubts have been cast upon their meteoric origin.

There is a fine collection of aerolites in the Natural History Museum, South Kensington. The Strathmore meteorite is a splendid specimen in the Royal Scottish Museum, Edinburgh. It was seen to fall, and was picked up, on 3rd December 1917.

It has been often suggested that new, or temporary, stars may owe their brilliant outburst of brightness to heat developed when the star penetrates those masses of gas which we call true nebulæ, which are to be found scattered over the Milky Way, the very part of the heavens where new stars are always situated, a most remarkable coincidence.

VII

Novæ, or New Stars.—Among all the wonders in the heavens there are few so rare, so unexpected, so surprising, or so subversive of preconceived notions about an unchanging universe of stars, as the sudden appearance, within less than twenty-four hours, in a well-known constellation, of a new star outshining all those that were in the sky on the previous night. Such a nova burst forth in the constellation Aquila, the Eagle, on the 8th June 1918, excelling everything of the sort recorded since the year 1604. About thirty

of them, not all so bright, but all seen by the naked eye, have been recorded in history.

Hipparchus, the greatest of Greek astronomers, in the year 134 B.C., was so much surprised by a new star that he then set to work to catalogue all visible stars, so as to check them in future.

In 1572 the same thing happened to Tycho Brahe, the greatest practical astronomer who ever lived. His own words tell the tale : "One night when I was examining as usual the celestial vault, the aspect of which is familiar to me, I saw, with unspeakable astonishment, near the zenith in Cassiopeia, a star of extraordinary brightness. Struck with surprise, I could hardly believe my eyes. To convince myself that there was no illusion I called the workmen occupied in my laboratory, and asked them, as well as all passers-by, if they saw, as I did, the star which had so suddenly made its appearance. Its brightness could be compared only to Venus in quadrature. It remained visible in the day at noon." It did not disappear completely until 1574, and is believed to be still visible in large telescopes, "smouldering where it once blazed," as a reddish variable star of the eleventh magnitude.

In A.D. 1604 Kepler and Galileo saw a nova as bright as Jupiter. Another bright one was seen in 1670, and no others till the middle of the nineteenth century, when, in 1866, a star of the second magnitude appeared in Corona Borealis.

Edinburgh can boast of a townsman, Dr Anderson, who has the unique distinction of having been the first discoverer of two brilliant novæ. He loves the stars, and habitually looks out of his window at them in the middle of the night, and "calls them by their names." As a result of this habit, on 1st February 1892, he sent an anonymous post card to Dr Copeland, the astronomer at Blackford Hill, imparting the astonishing information that a new star was shining in the constellation Auriga.

On 22nd February 1901 he was again rewarded for his patient watchfulness by discovering a nova in Perseus, equal to Algol, and the next evening exceeding Capella in brightness.

Needless to say, astronomers have attacked these surprise visitors, as well as other less conspicuous novæ, with all the resources of modern observatory instruments. In several cases novæ have been found depicted upon photographic plates taken on dates before the

novæ were visible to the eye. Their great feebleness, twenty-four hours before bursting into full splendour, was thus established, and suggests the consumption of terrific energy to produce such a development of heat in so short a time.

The spectroscope, however, has been the most important instrument for this research, and the appearance of each new star, even minor ones, led to improvement in the instrumental equipment. So that in 1918, when the dazzling splendour of Nova Aquilæ (3) surprised us, nearly every great observatory in the world was well prepared to record the marvellous changes of spectrum going on from night to night during many months—even years. The results gained from Nova Aquilæ exceed in importance those of all previous novæ.

In 1866, Sir William Huggins' recently mounted stellar spectroscope told us that the outburst of light in Nova Coronæ was due to a blaze of hydrogen gas. But the spectroscope performs another function besides detecting the chemical elements. Here only the bare fact may be stated, marvellous as it is. The spectroscope enables us, by measuring the displacements of spectrum lines, to learn the speed with which a source of light, like a star, is approaching or receding from us. Thus in 1892 Dr Anderson's first nova (the one in Auriga) told us, by spectroscopic evidence, that, compared with the hydrogen in that star causing the outburst, the other materials in the star were approaching us at the enormous velocity of eight hundred and eighty kilometres (or five hundred and fifty miles) a second. And a similar result has been derived from all subsequent novæ.

The conclusion to be drawn from this is that the light of new stars comes from two separate parts that are moving relatively to each other, with the enormous velocities of hundreds—and in some cases thousands—of kilometres per second.

It is here that the analogy of meteors has come in. The shooting-star itself is in rapid motion, and the luminous trail is at rest in the atmosphere. The star and the trail would be inseparable in the best telescope if the distance from us were very great. They would look like one source of light ; but the spectroscope would disclose their relative motion. It was therefore natural to suppose that, in the same way, a new star owes its sudden brightness to the friction

of a star traversing a gaseous nebula, just as meteors owe their light to friction against the attenuated gases in our upper atmosphere.

The complete facts of observation offer considerable difficulties to the acceptance of any one of the theories that are still being discussed by astronomers. They may not be dealt with at present. And here, now, must end this brief account of the three kinds of surprise visitors among the stars : comets, meteors, new stars ; a brilliant example of any one of which may reasonably be hoped for, if not expected, at all times.

The dates of the most remarkable comets of the past century are worth remembering : 1811, 1823, 1835 (Halley's), 1843, 1858 (Donati's), 1861, 1874 (Coggia's), 1880, 1881, 1882, 1901, 1910 (daylight comet), 1910 (Halley's).

The following meteor-showers are undoubtedly connected with comets :—

April (or Lyrids) meteors.
August (or Perseids) meteors.
November 12th (or Leonids).
November 27th (or Andromedids).

The brightest or most notable novæ appeared in the following years :—

		Magnitude
B.C. 134	Hipparchus star	−5
A.D. 1572	Cassiopeia	−5
A.D. 1600	P. Cygni	3·5
A.D. 1604	Ophiuchus	−4
A.D. 1670	Vulpecula	+3
A.D. 1866	T. Coronæ	+2
A.D. 1876	Cygnus	+3
A.D. 1892	Auriga	+4·5
A.D. 1898	Sagittarius	+4·7
A.D. 1901	Perseus	0
A.D. 1903	Gemini	+5·1
A.D. 1910	Lacerta	+5
A.D. 1912	Gemini	+4·5
A.D. 1918	Aquila	−1·5
A.D. 1920	Cygnus	+1·2
A.D. 1925	Pictor	+3

CHAPTER X

DARK STARS

I

NEARLY a hundred years ago a great astronomer said with truth : "We have no reason to suppose that luminosity is a necessary property of cosmical bodies. The visibility of countless stars is no argument against the invisibility of countless others." He said this to dispel the opposite opinion then held by many astronomers. To-day, in 1926, the whole sky seems to be crowded with multitudes of dark stars, all discovered since that astronomer wrote his protest.

The story of their discovery goes a long way back, and is only one part of the greatest discovery in celestial dynamics : that there are innumerable *solar-systems among the stars*, governed by the same force of gravitation that we are accustomed to on our earth, and in our solar system. But we have no direct information as to the existence of planets revolving round other stars than the sun.

II

Solar Systems among the Stars.—There are two pairs of incomparably fine stars, fairly wide apart, which always attract attention : one pair in the Northern, the other in the Southern Hemisphere. We, in northern latitudes, can always include among our friends the twin-stars Castor and Pollux, a pair of magnificent golden stars serving as two of the beacons beside that highway of the planets, the ecliptic. Our friends at the antipodes, on their part, are captivated by the two still more brilliant stars, Alpha and Beta of the Centaur, pointing to the Southern Cross.

In neither case has any bond of attraction been found connecting them like that which binds together our sun and planets, for the two stars are in each case separated by inconceivable distances. These great pairs of stars are not what we call "double-stars," and are now mentioned only because, in each case, one of the pair is found to be a double-star and a prominent example of solar systems among the stars. Castor itself, when examined with a

small telescope, is easily resolved into two bright stars, one of the second magnitude, the other of the third, separated by a distance of six seconds of arc (equivalent to two inches, a mile away).

Castor is historically interesting because it was the first case of two stars found to be revolving round each other. Sir William Herschel (who died over a hundred years ago, 25th August 1822), in his great thirty-year stellar survey at the end of the eighteenth century, constantly measured double-stars, to get their distance apart, and the direction of the line joining them. In the course of these observations he found the configuration of the doublet, Castor, to be regularly changing. He came to the conclusion that the two stars formed a "binary" system revolving in a period which he then estimated at over a thousand years.

This binary has become still more interesting of late years, for it has been found, by a most ingenious method of using a spectroscope, that each star of the pair is itself a pair of stars, revolving round each other, and making up a quadruple system of suns. The great pleasure we derive from Herschel's discoveries of the well-known solar systems among the stars lies in the fact that, to all appearance, these stars are revolving, like our planets, under the influence of the same force of gravitation which, upon our world, gives weight to everything we handle. Newton had extended the influence of this force throughout the solar system, and from Herschel's discovery it followed that the same force extended even to the distant stars, and might thenceforth be considered a *universal* force of gravitation.

An observer in the Southern Hemisphere can study Alpha of the Centaur in the same way as we can study Castor of the Twins. It is an easy double-star for moderate telescopes. The components are brilliant stars of the first and second magnitudes, and they revolve round each other in eighty-one years. Halley discovered its double character in 1689. Since then the distance and position-angle of the two stars have been measured through nearly three revolutions. So we know with some accuracy the orbit that is being followed, and astronomers can draw conclusions. The two component stars of Alpha Centauri are sometimes as close to each other as Saturn is to the sun—about a thousand million miles. Their greatest distance apart is three times as much. They

are nearly the same size, though one is rather more brilliant than the other. The brighter of the two not only contains just as much matter as our sun, but shines only a little brighter than it, and the spectrum proves the star to contain the same materials, probably at the same temperature, as our sun.

It is a wonderful consequence of Newton's law of gravitation that we should be able to weigh the stars when a pair of them form a solar system of their own. Generally it has been found that any two such stars do not differ greatly in mass, and, on the average, each is about equal to the sun. Some of them, however, may be ten times as massive, exceptional ones even more. These results are derived from a rather limited number of binaries.

III

It is easy now to understand the great interest of double-stars to a man who owns a telescope. Even before he has made any measurement they interest him on account of the beautiful contrasts of colour often displayed by such a pair of gems. Moreover, the close double-stars form one of the finest tests for the performance of a telescope ; and in this way amateurs get great pleasure in comparing the performances of rival telescopes.

Some double-stars can be seen even without the aid of a telescope. Mizar is the Arabic name for the middle star in the tail of the Great Bear. A companion star, called Alcor, can be seen close to it with the naked eye. Again, beside our bright-eyed friend Vega is Epsilon of the Lyre. Close to Vega two small stars can be seen, forming a regular triangle with it. Once recognized, they become a sure and useful sign that the bright star we are looking at is really Vega. One of these two small stars is Epsilon. When attention is fixed upon it there is little doubt of its being double. Even if the stars be not seen separate, they look like an elongated star, owing to the double character. An opera-glass will make this quite clear. A moderate telescope shows each of these two stars of which Epsilon Lyræ is composed to be itself double ; and their revolution round each other has been proved. Here, as with Castor, we have a quadruple system of revolving stars.

Many catalogues of double-stars have been made, and, for large

telescopes, none is included whose distance apart exceeds five seconds of arc. Using this standard, it appears, from the latest counts, that throughout the heavens about one star out of eighteen can be seen to be double. These have not all, however, been proved to be "binaries"—a term applied only to those double-stars which have been shown to revolve round each other, thus establishing a physical connection.

IV

The discovery of unsuspected solar systems among the stars is one of the greatest triumphs of that marvellous instrument, the spectroscope. Its original purpose was for finding out the chemical elements contained in anything. Thus we discover that many stars certainly do contain hydrogen in their composition, and others helium, or calcium, or metals. Some contain titanium oxide, and those of one class are proved to have carbon in their atmospheres. The existence of these elements is proven when the light from a star is drawn out into a long rainbow-coloured line or spectrum, by looking at it through a glass wedge or prism. For this coloured line is interrupted here and there by a missing colour; and the positions of these interruptions, or black gaps, in the spectrum indicate the chemical elements existing in the star's atmosphere.

It is surely a wonderful thing that the splitting up of a star's white light into its constituent colours by a prism should inform us of its chemical constitution. But there is an even greater marvel in the certainty with which a slight shift in the position of these black gaps towards the violet or towards the red end of the spectrum informs us whether the star is moving towards us or from us, and tells us the exact speed with which it so moves, actually measured in miles per second.

The information given to astronomers who study the motions of the stars, by this astonishing power of the spectroscope, altogether eclipses, from their point of view, its power of chemical analysis. The unexpected part it has played in the discovery of solar systems among the stars, and of dark stars, forms one of the romances of astronomy.

The late Professor E. C. Pickering long ago earned the gratitude

of all who care for the stars by the original and fruitful directions into which he guided the energies of Harvard College Observatory, U.S.A., from the time when he first assumed its directorship. One of his greatest discoveries was connected with our friend Mizar in the tail of the Great Bear. In 1889 he was able to announce that his assistant, Miss Leavit, daughter of a distinguished English engineer, found that dark lines in the spectrum of the brighter of the two stars of which the visual binary Mizar is composed are periodically double, and in the intervals they are periodically single. The double spectrum proves that the light comes from two separate stars, so close together as to look like one. The relative displacement and duplication of lines in the two spectra, at regular intervals of time, proves that, at these times, the one star is approaching us and the other receding, compared with the middle point between the two stars. This could happen if the two stars revolve in a circle at opposite ends of a diameter. In that case, when one star is at its greatest distance from us and the other at its least, they would be in line, and neither of them would be either approaching or receding from us. At those regular intervals the double-star would show only one spectrum. Thus we understand the meaning of the fact that the spectrum-lines are alternately double and single.

Upon these lines of reasoning it became certain, after observations had been extended over a longer time, that the brightest component of the visibly double star Mizar, in the tail of the Great Bear, consists actually of two stars, revolving round each other in a period of three weeks ; that their distance apart is about the same as Mercury's distance from the sun ; and lastly, that their combined mass is twenty times that of the sun.

This wonderful discovery arose entirely from continued laborious and exact observations of the spectrum of the bright star Mizar.

Out of that discovery a new department of astronomy soon arose, and numerous spectroscopic binaries are constantly being added to the list. By careful and long-continued observation of the displacements of dark lines in the spectra of a great many stars, evidence has been accumulated indicating in many cases a periodic character in these displacements, due to the binary character of a great many of the stars examined.

The very first stars in which the spectrum lines were found to be periodically doubled, after Pickering's Mizar, were our old friends Capella and her bright neighbour Beta of the same constellation, Auriga, the Charioteer. None of these spectroscopic binaries has been seen as doubles in the telescope. Quite recently, however, a new method for testing and measuring such close doubles has been entirely successful in the case of Capella, and every astronomer rejoiced at this confirmation of the spectroscopic evidence.

In all of the cases hitherto mentioned the two stars of the system were *both* bright enough to show the spectrum with its lines. Not long, however, after the great discovery of double lines in Mizar, the spectroscope revealed to us a double-star wherein one of the pair was a black invisible star, giving no spectrum at all. Of course, whether the second star of a pair be bright or dark, the orbit is the same. And the spectrum lines of the bright star must be periodically displaced, to one side or the other, according as the star is approaching us or receding.

When both stars were bright the duplication of the lines was an easy test. But it was found possible, even without this help, to measure the varying shifts of spectrum lines belonging to the single bright component of a pair. When those shifts of lines were found to vary periodically, and with perfect regularity, there was no room for doubt that the bright star was revolving in an orbit by the attraction of an invisible companion. Spica, the bright star in the constellation Virgo, the Virgin, was the first star thus proved by the spectroscope to be revolving round a dark invisible star. Spica is a lighthouse on the ecliptic. Both Jupiter and Saturn were seen steering for it in 1922.

The discovery of a heavenly body, whose existence was unknown, by reason of its attraction upon one that is visible, strikes the imagination as a crowning triumph for astronomy and for the great law of universal gravitation. Everyone felt this at the time when Adams and Le Verrier discovered the exact position of a new unknown planet, Neptune, by the disturbance that its attraction exercised upon the outermost known planet in the solar system.

To discover the dark companion of Spica did not call for the profound calculations that revealed Neptune to us. But it involved

great delicacy in the instruments, as well as great patience in the observer. And we still feel the same thrill of admiration in the discovery of a dark star without seeing it.

The search with the spectroscope for new solar systems among the stars, by the varying displacements of their spectral lines, has been carried out with a diligence that has brought its own reward. It is now estimated that every fourth star in the heavens can, with our present optical means, be proved to be a spectroscopic binary. There must, of course, be many binaries that do not approach and recede from us, if the plane in which they move be perpendicular to the direction in which we see them (the line-of-sight). So we are all the more astonished at discovering how great is the number of these binary systems already disclosed to us. Every time we look upon Mizar, Capella, Castor, Spica, or Beta Aurigæ, our mind recalls this marvellous power of research that has come into our hands, and is filled with wonder at the immense number of solar systems among the stars already revealed to us.

V

In the case of a bright star revolving round an invisible companion, it is not difficult to understand that the invisible one must have a powerful attraction, and must be very large, to produce the result observed. And it is equally clear that, in exceptional cases, the black star may, once in each revolution, lie between us and the bright star of the pair. And since the black star is large, we might expect to see a total or a partial eclipse of the bright star.

No *total* eclipse of this kind has ever been observed, but a century before the invention of spectroscopes, periodical partial eclipses had been observed and attributed to their right cause—the revolution round each other of a bright and a dark star. A description of this occurrence must now be given.

Any evening towards the close of the year in our latitudes the W-shaped Cassiopeia can be seen overhead. A string of stars can be seen, from Cassiopeia to the Pleiades cluster, forming the constellation Perseus. The brightest star on that string of stars is called Alpha, showing a lovely field of view with a binocular, and there is another, called Beta, generally about as bright as Alpha, a little

to the right and farther from Cassiopeia. This is one of the most marvellous stars that can be seen with the naked eye. Its extraordinary behaviour may possibly have been known to the old Arab astronomers, for they gave to Beta Persei the name of Algol, which means the Demon.

Ordinarily, Algol is a second-magnitude star. It remains so for two and a half days at a time. Then during three and a half hours it loses three-quarters of its brightness, remaining at a quarter of its normal light for twenty minutes, and in about three and a half hours it again reaches the second magnitude, which it retains for two and a half days. Then once more it recommences its extraordinary performance. Anyone can see these changes quite easily with the naked eye. The eclipse theory was shown to be a sufficient explanation one hundred and fifty years ago. But this was not accepted as being finally proven until the spectroscopic shift of lines was found to be in accord with the changes of velocity in the line-of-sight, due to the revolution of two nearly equal stars, one bright, the other dark. Before the minimum phase the spectrum lines of the bright star are shifted towards the red, indicating its recession from us. After the minimum the shift is towards the violet, indicating approach. This has led to the general acceptance of the explanation of this type of variable star as being due to its eclipse by a dark companion comparable with it in size. About a hundred variable stars of the Algol type have been discovered, indicating the existence of about a hundred large but dark stars. The number of dark stars forming spectroscopic binaries is far greater.

VI

The spectroscope has given to us a knowledge of a great many solar systems among the stars, and also of a great many dark, invisible stars. It has done both of these things by showing up the periodic changes of approach to us and of recession from us in some stars. It takes no account of cross-motion—that is, of motion at right angles to the line-of-sight, of movements over the surface of the sky compared with other stars. The spectroscope cannot detect any motion except towards or from us.

Long before the spectroscope was known, astronomers had most

accurate instruments for finding the exact position of stars, and their minute changes of position from year to year. The great star Sirius, when thus studied, was found to be moving at a certain average rate, in a certain average direction. But its movements were subject to slow fluctuations ; and, in 1834, Bessel discovered that the exact amount of those fluctuations could be accurately foretold upon the assumption that Sirius revolves round a dark companion-star in about fifty years. It was then that he expressed the opinion that there is no reason why cold non-luminous stars should not be as common as hot bright ones, if only we had the means of discovering them. It soon became possible to predict at any date the exact position where the invisible companion to Sirius would be found if ever our telescopes should lead to its discovery.

Then a startling discovery was made. A telescope-maker, Alvan Clark, was testing the performance of a new and powerful telescope lens that he had made. To do this he examined the star Sirius, and was astonished to observe a minute star close to Sirius in a certain direction from it. He did not know where the suspected companion was, and the world of astronomy was astonished and delighted to find that the little star discovered by Alvan Clark was almost exactly in the predicted place.

After its first discovery it has not been difficult to find the minute companion even with a telescope of six or eight inches diameter, when the stars are well separated. This is not always the case. The two stars recede and approach in alternate half-revolutions. Every fifty years for a short time they are only two seconds of arc apart, too close to such a bright star as Sirius for seeing the small companion. This happened in 1894, when the present writer had the privilege of a night with the great Lick refractor in California. He utterly failed in his effort to see the companion of Sirius, and was heartily ashamed of the falling-off, as he supposed, in his eyesight, not knowing the exceptional circumstances, as he had then been for some years occupied with engineering, and not astronomical, affairs. His relief later was great when he knew that the small star was then invisible, probably, to those with the best eyesight in the world.

His companion at the Lick telescope that night was Professor Schaeberle, whose discovery, with the same telescope, two years

later, of a similar very minute attendant upon Procyon (the bright star to the east of Orion, above Sirius) caused a great excitement in the astronomical world.

For Bessel, when he announced to the world his belief in the existence of a dark companion to Sirius, extended his arguments to certain fluctuations in the proper motion of Procyon. Then, with the same confidence he had displayed in regard to Sirius, he announced that Procyon also is attended by an invisible companion. For many decades it remained invisible, until, in 1896, Schaeberle had the extreme gratification of discovering it with the great Lick telescope.

In both of these cases the feeble star has been proved to be nearly as massive as the bright star. Thus, in the case of Sirius, the bright star has a mass only two or three times that of its companion, but it sends out to us about thirty thousand times as much light.

It can now be understood how much more inspiring and beautiful the midnight sky becomes to him who has had the joy of reading about, and, still more, of beholding, the wonders revealed by the telescope and the spectroscope. For then he is able to see more in his mind's eye than is revealed to his unaided vision. This star and that star present to him vistas of solar systems among the stars, and of dark stars that can never be seen by human eye. Mizar, Alpha Centauri, Spica, Algol and Sirius become to him emblems of binary systems or dark stars revealed to him by the various processes that have now been described.

The existence of countless dark stars in the sky startles us at the first announcement, but appears most reasonable and probable after a moment's reflection. It may be interesting to conclude by stating that, quite recently, two of our ablest mathematicians, who are authorities on speculative astronomy, have each declared his belief that dark stars are about two or three times as numerous as bright stars.

CHAPTER XI

COLOURED STARS

I

UNTIL we know the names of flowers it is difficult to remember them by differences in their blossoms, leaves and stalks, or to group them by colour, shape, size or habitat. It is the same with the great variety of birds. So it is also with the stars. It is only when we know some of the stars by name that the sight of any one of them calls to our mind its individuality ; and this power of placing it in our thoughts reminds us of the increasing intimacy of our friendship with the stars.

It is then that we begin to attend to the differences in brightness, colour and position among the other stars. And we recall what we know about their distances from us ; and their minute motions, perhaps in company with a group of stars ; and the movements towards and from us, revealed by the spectroscope. In some cases our interest in the star is increased by knowing that it is double, one of a pair of suns that are revolving round each other, a kind of solar system. And so it goes on.

To make this clearer, let us take any one star, and think for a moment of all that is meant by its name, after our intimacy with it has increased even a little. The three stars of Orion's belt point to Sirius, the Dog-star. The very name is associated in the mind of a star-lover with many qualities. It is the brightest star in the whole heavens, twelve times brighter than a first-magnitude star like Aldebaran at the other side of Orion's belt. This great brightness is certainly due in part to its dimensions and its high temperature. But also the brightness of a star diminishes with the increase of distance, and Sirius is the nearest to us of all stars we can see from our latitude without a telescope. Hence its great splendour. Then we think of its comparatively large motion among the other stars. In this feature the only bright stars competing with it are old friends of ours, Arcturus, Vega, and Alpha of the Centaur. But Sirius appeals to us most of all, because we remember that it is one of a group of travellers. Far removed as it seems to be from the Plough, yet, with the stars of the Plough, it forms one of a cluster of stars

all speeding with uniform velocity towards the same region of space. This is not the only wonder about its proper-motion, for one of the first thoughts we have in association with the name of Sirius is its connection with a companion star, the two revolving round each other once in fifty years. And the feeble companion was discovered, before it had ever been seen, by the fluctuations, caused by its attraction, in the proper-motion of Sirius. Then again, although it is so much nearer to us than other stars, yet it is so distant that if an explosion were to take place there, nine years would elapse before the effect could be seen by us ; although the light set up by the explosion would be travelling towards us, all these years, at the enormous velocity of one hundred and eighty-six thousand miles every second.

These are some of the thoughts associated with Sirius even at this stage of our intimacy. And so it is with all of our star-friends. The name of each of them is associated with peculiarities of character. Each forms a chapter of natural history, after we have begun to notice and remember what we see. The name Arcturus means now for us a flight through space at a speed of two hundred and seventy miles a second. Mizar, in the Plough, cannot be named without our thinking of it as the first-known double-star, of which the brighter one consists of a revolving pair, the first that were ever revealed by the spectroscope, though never seen separate.

Algol is for us the star accompanied by a dark companion which gets between us and the bright star every three days, and reduces its light to a quarter. Vega is the most beautiful star in the sky, steel-blue, making, with its two small attendants, a fine little regular triangle. It is an important star, because it lies nearly in the direction towards which our solar system is travelling ; and, moreover, after twelve thousand years, it will be our Pole-star to which the earth's axis will be pointing.

So it goes on as we acquire the habit of taking notice, and soon there remains no part of the sky untenanted by stars that seem almost to talk to us and tell us about the natural history of the heavens.

II

The brightness of Sirius must always be its greatest claim upon our attention ; but the habit of noticing differences leads us to note its bluish colour too. And soon we arrive at the conclusion, quite unnoticed before, that stars differ in colour. Of course everyone knows of the fiery red colour of Mars, especially when seen in opposition (that is, when opposite to the sun, or in the south at midnight). In the constellation Orion, Rigel (Arabic for leg) is brilliantly white. But Betelgeuse, in Orion's shoulder, has a distinctly red flare ; so also has that bright star, not far from it, Aldebaran in the Bull. Capella, seen overhead in our latitude when Orion is in the south, is of an intermediate colour, more yellow. So are many others. Alpha and Beta Centauri (pointers to the Southern Cross) are conspicuously golden stars, delighting our kinsmen at the antipodes. And when we come to think of it, if we are able to look directly at the clear, unclouded sun, it, too, has the yellowish tone of Capella or Alpha Centauri.

The white stars like Sirius, and still more Vega in the Lyre, appear, perhaps by contrast with the others, to have a steel-blue tint, but they are really very white. The brightest star at the other end of the scale, which is most intensely red, is Antares in the Scorpion. This bright star is never very high in the sky for us northerners. It is best seen in the south at midsummer towards midnight. It is the middle and brightest of three stars in line (thus resembling the configuration of Altair in the Eagle, the line of three stars that point to Vega).

The bright Arcturus, towards which the Bear's tail points, clearly differs entirely in colour from the steel-blue Vega, generally to be seen at the same time as Arcturus. It is orange, approaching in colour to the red glow of Aldebaran. Stars, then, differ in colour, being of all shades, from an almost bluish white, through yellow and orange, to a deep red or even crimson. And they can each be given their place in a natural scale of colours.

III

After a person's attention has been drawn to these differences in colour among the very bright stars, he naturally points his

opera-glass or telescope to see the colours of fainter stars. If he should have a friend who knows the star places, and what to look at, he is fortunate, and he discovers a new field for his curiosity, of unexpected beauty and interest.

His first search for brilliant colour might well be directed, while Orion is under scrutiny, to a star called R in the constellation Lepus, the Hare. Imagine a diagonal line drawn through Orion's belt from Betelgeuse to Rigel, and carried on half as far again. At that part of the sky a small glass will soon pick up the brilliantly coloured R Leporis, of a deep crimson colour. It is a variable star of long period, and while changing its brightness it also changes its colour, like a chameleon, from red to orange.

Then again, as Leo, the Lion, may be above the horizon at the same time, an almost equally fine deep red could be detected in R Leonis. This is another long-period variable star, near to Regulus in the handle of the sickle-shaped string of stars at the head of the Lion. R Leonis is west from Regulus, at a distance equal to the handle of the sickle. This star shows up its crimson colour, perhaps even better than R Leporis, because it contrasts so well with a white star in the same field of view, with any telescope of low power.

After anyone has thus made a start with a small telescope, a wide field of exploration lies open to him. With the aid of some guide-book to the celestial objects, such as Webb's *Celestial Objects for Common Telescopes*, his small telescope will be directed on every clear night to coloured stars in those constellations that happen to be above the horizon. And he will soon notice that most sparkling contrasts are to be found among the double and multiple stars.

For example, towards the close of the year, when the great Square of Pegasus is conspicuous, he will find that Gamma of Andromeda is a beautiful object. There is no difficulty in finding it. From the north-east corner of the Square of Pegasus three bright stars run in a straight line, underneath the W of Cassiopeia to Perseus. These are the brightest stars in the constellation of Andromeda, and the third one is Gamma. A telescope shows it to be double, a large orange star and a smaller emerald-green one. A more powerful glass resolves the emerald star into two, one blue, the other yellow. This is one example of many multiple-coloured suns that give delight to all who start upon the exciting sport of hunting up double,

and multiple, and coloured stars, with the help of a telescope, a guide-book and, perhaps best of all, an experienced friend.

While our little telescope is in use let us turn it from Andromeda to the neighbouring constellation Perseus. This is the string of stars extending nearly from the W of Cassiopeia to the Pleiades cluster in the Bull. Alpha is the brightest star in Perseus, and the group of stars round it deserves examination, even with a binocular. Half-way from Alpha Persei to Cassiopeia is a star called Eta of Perseus. This is a brilliant double-star, one star a beautiful red, the other dark blue. This wonderful contrast of colour is by no means uncommon in many parts of the sky. It has long been noticed by astronomers that when the two components of a pair are about the same in magnitude they are generally the same in colour; and that the probability of colour-contrast increases with increasing difference in the brightness of the companions, the fainter star in nearly every case being the bluer.

Sir John Herschel, in his observations made at the Cape of Good Hope, described a cluster near Kappa in the Southern Cross as "an extremely brilliant and beautiful object when viewed through an instrument of sufficient aperture to show distinctly the very different colours of its constituent stars, which give it the effect of a piece of fancy jewellery." Out of the one hundred and ten stars he noted in the cluster, only seven exceed the tenth magnitude. Three are described as greenish white, two as green, one red, one blue-green, and one ruddy.

We cannot analyse their beauty, or say why these objects please us much more than the coloured flashings from a diamond, but so it is. Moreover, an astronomer often has an uncomfortable feeling that some of the contrasts of colour originate in his own mind. If so, the beauty is none the less. The mind seems occasionally to seek to catch the complementary colour, just as a white "incandescent" gas-lamp in the street is looked upon as green among the common gas-lamps, which are more red.

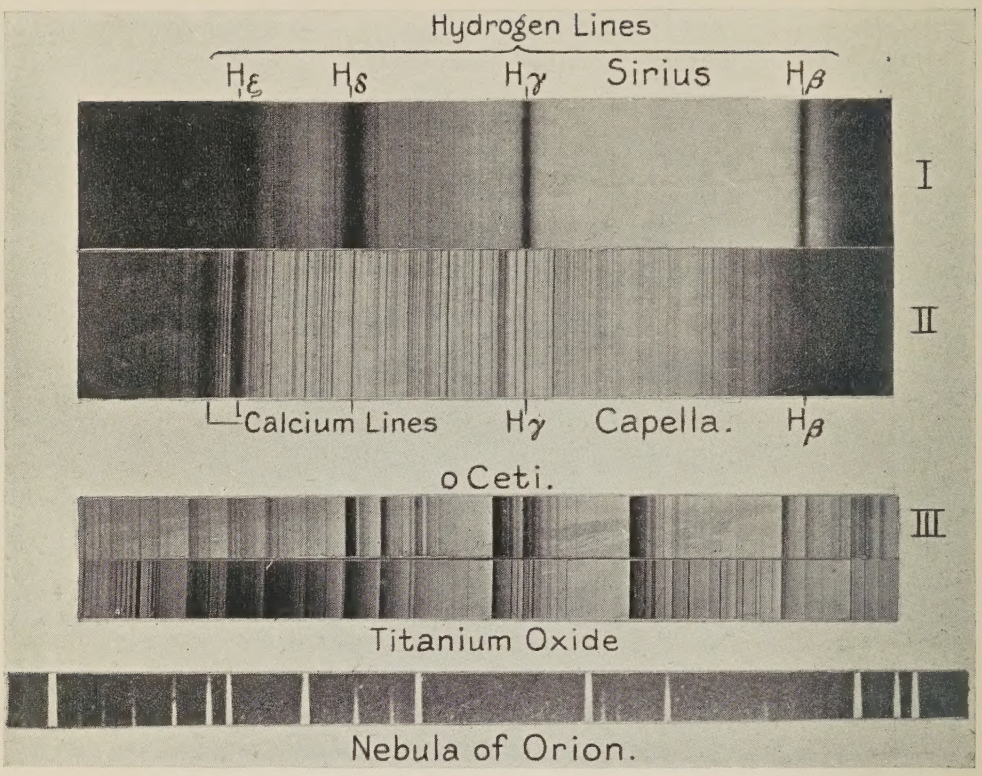
IV

Some of the coloured double-stars are called binaries, being those that revolve round each other under gravitation. Any of them may,

for all we can tell, be the centres of solar systems containing inhabited planets. There the supposed human beings would live in a magical world of colour, where the red sun sets, and a blue or emerald sun remains shining upon the world, as when we look at woods and fields and mountains through blue, orange or rose coloured glasses.

When we have the good fortune to see with a telescope these sparkling gems, the imagination is apt to run riot about the inhabitants of any planets that may belong to these suns. During the time that a blue sun is eclipsing a red one, what weird alternations of colour may transform the aspect of a country scene ! On such a planet there may be long periods with no darkness at night. For twelve hours a sun may have flooded the outer world and the interior rooms of the home with rose-coloured tints ; and after it sets there may follow twelve hours of green light from another pair of suns, one blue and the other yellow. Then a moon may pass and eclipse one or other, leaving people in a world of blue or yellow light. That moon itself may be lighted by the two or three suns, and may show varying tints of combined colours over its surface. Then again, how inconvenient must it be to have to do with both "red solar time" and "blue solar time" at the same hour! And yet if there be people to see these things they probably accept them as being what ought to be expected, rather than as a heavenly wonder.

If anyone is led by these remarks to look for the many-coloured suns that exist among the double and multiple stars, it is unlikely that his curiosity will lead him no farther. Even with a small glass he would often be tempted to try new hunting-grounds. He might take a delight in identifying some of the wonderful cloud-spots among the stars, whether spiral nebulæ, or planetaries, or clusters. He might then look forward in hope of seeing their details some day in a powerful telescope, or at least he might take an interest in the wonderful photographs produced by the giant-telescopes of the world. In this manner many a man, having begun to use a telescope to pick up double-stars and coloured suns, has extended his field of operation to such an extent as to have become an acute observer and discoverer of new wonders in the heavens.



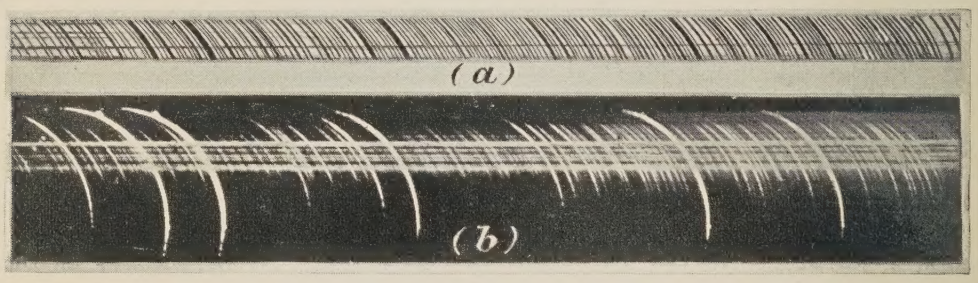


PLATE XI.—SECCHI'S SPECTRAL TYPES, I, II, III

Spectrum of Titanium Oxide; Spectrum of Orion Nebula. Bright lines in (*b*) Flash Spectrum of the Sun, almost totally eclipsed, and corresponding (*a*) dark lines five seconds earlier

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V

In the very early days of the spectroscope, in the middle of the nineteenth century, Father Secchi, at the Vatican Observatory in Rome, used a spectroscope to make a general survey of stars, to find out what they are made of. (One of the writer's happiest reminiscences is of an evening spent at Rome in 1871, when Secchi exhibited to him the brilliant spectra of Sirius, Capella, Betelgeuse, and other stars, with his splendid prism and telescope.) In this way Secchi made a grand discovery about the colours which we have noticed in different stars. He found that stars which differ in colour differ also in the chemical elements exhibited in their spectra. The white or bluish white stars, like Sirius, Vega and Spica, all have one class of spectrum, crossed by a few broad dark lines due to hydrogen in the atmospheres of these stars. This spectrum is quite different from the solar spectrum, where the element hydrogen is by no means so intensely shown. The solar spectrum is characterized by innumerable dark lines that do not appear in the Sirian spectrum. Among the most intense is calcium ; and we also find evidence of the existence in the sun of about forty of the metals found upon our own world. Only the heaviest known metals are absent from the solar spectrum ; so that gold prospectors need not go there.

Secchi found that about half of the brighter stars look white, and have hydrogen spectra like Sirius. The remaining half have nearly all got a spectrum closely resembling that of the sun, with calcium and other metals as the chief components of these stars. Thus it appeared that the sun is really a star of Secchi's second class, which includes all the yellow stars like Capella, Altair or Alpha Centauri (Plate XI.).

Then he found a third class of spectra which accounts for all of the conspicuously red stars like Antares, Aldebaran and Betelgeuse. These stars have a spectrum which is dominated by an oxide of titanium, a substance of so little importance, or special character, as to cause great astonishment that it should be the dominant material shown by a whole class of red stars.

Finally, Secchi added a fourth class, certain telescopic stars of a deep red colour, whose spectrum proves the existence in their atmospheres of some compounds of carbon.

Most of the bright stars belong to Secchi's Class I. or Class II. —the white or the yellow stars. Classes III. and IV., both red, are far less numerous.

VI

Why, then, do these different classes of stars send out light of different colours? Is it possible that the light emitted by the bright body of the star is in every case pure white, containing all the colours in due proportion to give a pure white? Is the colour then given because the atmosphere of the star absorbs more and more of the violet, blue and green colours, and leaves more red? This might certainly give the increasing red tint as we pass in review Secchi's four classes of stars. We all know that when the sun is near the horizon, and its light traverses an unusually long path through our atmosphere, the blue colours are absorbed by our atmosphere, and the sun looks red. May not the atmospheres of stars perform the same function? This is an obvious suggestion, and may contain much truth.

But the current opinion is rather different, and is already supported by a good many observations made upon stars. The idea is that the colour of a star depends on its temperature. All of the stars are suns, but they need not be all at the same temperature as our sun. If we heat a poker in a furnace, and draw it out of the fire now and then to examine it as the temperature rises, it is at first a dull red, then orange, then yellow, and it may ultimately reach a white heat. Thus the different colours of stars are imitated. Moreover, we notice that on throwing any substance into the furnace—metal or hard stones, soft stone or coal—after reaching the temperature of the furnace they all shine with the same colour, so that the colour of the light emitted depends upon the temperature.

It would, however, be absurd to suppose that, in changing colour from dull red to white, the poker acquires the temperature of Secchi's different classes of stars. Colour is a question of comparison, and is largely subjective. The poker, when apparently white-hot in the furnace, looks a dull red when compared with the dazzling white on the tip of one of the carbon rods in the electric arc-light.

There is no doubt, however, that temperature might well be

the true explanation of star-colours, at least in most cases. Studies have been made in the laboratory of the average colour that is emitted by a hot substance at different temperatures. Then, it is suggested, the average colour of any star tells us the temperature of the stars. Many plans have been devised for estimating the average colour. One of these deserves notice here.

The *visual* magnitude of a star is got by comparison with stars whose brightness has already been measured by eye, with an instrument called a photometer. The *photographic* magnitudes are compared by measuring the diameter of the star-images developed on a photographic plate. Now this photographic image is produced principally by colours in the star's light that belong to the violet or blue end of the spectrum, and by the invisible colours beyond the violet. But the visible colours are different, and nearer to the red end of the spectrum. So it happens that the photographic magnitude is a measure of brightness in an average of colours at the blue end of our scale of colour, while the *visual* magnitude is in an average of colours that are nearer to the red end of our scale. Thus when we find a difference between the photographic and the visual magnitude of a star, that difference tells us the proportion of blueness and redness in the star's light. We can then estimate the average colour of a star, and our laboratory tests enable us to give at least a shrewd guess at the temperature of the star.

There are many other ways of getting the average colour of a star, and so of estimating the temperature, which is higher or lower according as there is a larger proportion of blue or of red in the spectrum of a star. This branch of astronomy is quite new, but already there are many astronomers engaged on measuring what is called "colour-index" as a guide to a star's temperature.

Another guide to temperature is found in the relative darkness of the dark lines in a star's spectrum. It is found that some of these lines get darker and others lighter with increase of temperature. So that a comparison of the darkness of two such lines gives an indication of a star's temperature. In fact, the wonderful powers of that modern instrument, the spectroscope, go far beyond discovering chemical elements that exist in a star. This was what excited our admiration and wonder when it was invented. But it also tells

us, by slight shifts in position of spectrum-lines, the speed with which any star is approaching or receding from us. And now it is trying to tell us the actual temperature of any star.

VII

There is thus found to be a grading of temperatures through Secchi's classes of star-spectra : the white or bluish stars being hot, and the red ones cooler. Now there is certain evidence of some localization of the stars according to their spectra. The stars containing helium are grouped in the constellations Orion and Argo. The white stars, like Sirius, predominate in the Milky Way, and the yellow stars, like Capella and our sun, frequent regions of space that are not so distant. Wolf-Rayet stars are on the Galactic equator. (All the same, there are many wanderers of one class into regions preferred by another class.) If it be true that each spectral class has a different temperature, are we to suppose that the different regions of space have different temperatures ? Such a supposition has not been seriously entertained by astronomers. They are at present inclined to the belief that all stars are made of the same materials, and that every star, during its life as a star, passes through the whole range of temperatures until it becomes too cold to emit any light ; and that the particular substances in the star which absorb some colours and produce dark lines in the spectrum vary with the temperature, for some reason not at present very clearly understood.

In this way many of our best astronomers are engaged on a very promising line of study. They are actually trying to examine the life-history of each star. According to them, Capella was not always a yellow star ; it once was red. Antares will not always be red, but will, some day, be as white as Sirius. And so with the others. The sun will show us titanium oxide as the principal component in its spectrum at some future date.

This speculation opens up a completely new view of the stars above. Already we have had to give up all thoughts of their being fixed and immovable. And now the theory that is for the present most generally accepted tells us that, like all else in creation, the stars themselves are in process of change towards ultimate decay ;

and when that time comes they all, and not last of them the sun, will be extinguished, and we shall have a dead universe.

That is the end, according to the speculations of this still very early century in the world's history. Even though it be all true, who can deny that revivifying powers may later be discovered, acting like the effect of spring upon the winter decay of trees and flowers, and bringing eternal hope and trust into the hearts of future generations, enlightened by that greater knowledge which we, pioneer seekers after truth, are groping for. For we are well aware that the whole truth can be manifested only, if at all, after many more centuries of laborious but engrossing study of the laws by which our universe is ruled.

CHAPTER XII

STARS THAT BRIGHTEN AND FADE

I

It is not every night that we see the stars in their full glory from the British Isles. There is often some cloud or mist even in the open country. Anywhere near a town the smoke and the artificial light in the streets dull the stars and obliterate the fainter glow of the Milky Way. Perhaps this makes us all the more appreciative of an exceptionally bright starry night, oftenest experienced in winter. Those of us who can recall clear nights spent on the Higher Alps, above the gross, dust-laden lower strata of the atmosphere, or those who have experienced the still clearness of the desert air, do certainly envy the lot of the old Arab astronomers, who, every day of their lives, could look forward on any night to a certain and clear view of any stars they desired to examine, or whose brightness they wished to estimate.

Yet it has been found by astronomers that the telescopes of Greenwich Observatory, on a good night, are favoured with a more tranquil medium in their own atmosphere than in many more vaunted climates, and are to that extent in the most favourable condition. So our climate is not so very bad for astronomy, as its history can well testify.

At first it seems almost incredible that we never can see at one time, with the unaided eye, more than about two or three thousand stars. Of course we have only half of the stars above the horizon at once, and near the horizon faint stars are dimmed. Still, the number two thousand does seem to everyone an underestimate. The explanation of this was first given by the late Principal Forbes when, as a boy of seventeen, from under Italian skies, he sent an anonymous letter to Sir David Brewster, in Edinburgh, who published it in his *Edinburgh Journal of Science*. The fact is that the middle part of the retina of our eyes is less sensitive to light than other parts. Hence in a casual glance at the stars we see a great number indirectly, which disappear when we look straight at them to make sure, before counting them. This is the reason why, without clearly seeing them, we really do get a

glimpse of many more stars than the two thousand or so that we can count.

The brightest stars are spoken of as being of the first magnitude, and the faintest seen by most of us are called sixth-magnitude stars. Those of intermediate brightness are second, third, fourth or fifth. This scheme was adopted by the ancient Greeks, and is still used. In order to give it more precision we now say that each magnitude is two and a half times brighter than the next following ; or that, when one star is one hundred times brighter than another, there is a difference of five magnitudes between them. If the number two and a half be multiplied by itself five times, it gives nearly a hundred. So the two statements are almost the same.

The smallest star that can be detected with a very large telescope is of about twenty-first magnitude—a difference from a first-magnitude star of twenty magnitudes. Now, if two and a half be multiplied by itself twenty times, the result is about one hundred million. So a first-magnitude star is a hundred million times brighter than the faintest star we can see with a powerful telescope. Specialists distinguish differences of a tenth, or even a hundredth, of a magnitude. About twenty stars are generally spoken of as first-magnitude stars. The star which is the nearest to being of first magnitude, exactly and no more, is Aldebaran. Vega is a whole magnitude brighter, and is properly described as being of zero magnitude. Sirius is so bright as to have a negative magnitude $-1{\cdot}6$. The sun's brightness is the negative magnitude -26.

Almost all the first-magnitude stars are probably known to the readers of these lines. Capella, Arcturus, Rigel, Procyon, Altair and Betelgeuse all lie, in magnitude, between Aldebaran and Vega. People in the Southern Hemisphere have, in addition, the brilliant Canopus, reaching the meridian at nearly the same time as Sirius ; also Alpha and Beta of the Centaur, the " pointers " to the Southern Cross ; and Alpha, the brightest star of the Southern Cross ; besides Achernar, in Eridamus—all brighter than the first-magnitude star, Aldebaran.

The principal stars in the Plough and in the Great Square of Pegasus are second magnitude, those in Orion's belt are third magnitude, and most of the stars in the Little Bear are fourth or fifth.

Nineteen stars are generally included in the first magnitude, fifty-nine in the second, one hundred and eighty-two in the third, five hundred and thirty in the fourth, one thousand six hundred in the fifth, and four thousand eight hundred in the sixth. In fact, there are about three times as many stars of any one magnitude as there are of the next brighter magnitude. Down to the fifteenth magnitude there are altogether about a hundred million stars.

This distribution in number and brightness is not very far from what we should expect if all the stars were uniform in size and in temperature, and were all scattered at equal distances apart. But, on examination, it is found that they are not all of the same size ; nor are they at the same temperature. On the contrary, some stars, such as Rigel and Sirius, seem to be white-hot, while others, like Capella and our own sun, are only yellow-hot, and are not so shining. Some stars, like Aldebaran, though only red-hot, are so enormous in diameter that they seem to us as bright as some of the white-hot stars that are at the same distance from us.

Betelgeuse, in Orion's shoulder, already to all of us a familiar star, introduces the special feature of the present article, for its magnitude is uncertain. This peculiarity of certain stars is one of the most marvellous phenomena in the whole of astronomy. Betelgeuse brightens and fades in an average period of eleven months, but its variations and period have no perfect regularity. In 1915 it was for some time much fainter than usual, decidedly feebler than Aldebaran of the Bull. In September 1919 it was brighter than Vega of the Lyre, or any other star in our sky except Sirius, the Dog-star. For some months its brightness then lay between Rigel, in Orion's leg, and Procyon, to the left of Orion and above Sirius. In December 1921 it was about equal to Aldebaran.

Readers of this statement will notice that, without any knowledge of astronomy, an eager watcher of the stars might have made for himself these comparisons, and so have convinced himself that Betelgeuse, the reddish star in Orion's shoulder, is a "variable." He may have noticed the same fact about Algol in Perseus, whose variations, however, are perfectly regular. By merely taking note of what he sees, anyone might find among the stars some that brighten and fade, regularly or irregularly.

Standard catalogues of star-magnitudes have been made by careful

comparisons. Thousands of stars were thus compared in relative brightness with Polaris. All other stars are compared with stars in these standard catalogues. They then become new standards, with which we can compare the changes in brightness of a variable star like Betelgeuse or Algol.

In this way a new field of work upon the stars has been opened up during the last half-century. In this country by far the most valuable results have been due to a group of amateurs, members of the British Astronomical Association, who publish the wonderful, surprising results in their journal and reports. These marvellous ups and downs in the light of some stars still baffle the human intellect. This only whets our appetite to observe and to learn more about their extraordinary behaviour.

II

New Stars, or Novæ.—Of all the variable stars, there is none that approaches new stars in the magnitude and suddenness of their brightening. (Their performances have already been briefly described in Chapter IX.) There is a general resemblance in their antics, though with occasional diversities.

One of the most useful undertakings of Harvard College Observatory, U.S.A., is the exposure of many photographic plates all over the sky on every clear night. Thus, when a new star bursts forth, photographs of that part of the sky, just before, can usually be found, and the star's brightness can be estimated. These records inform us that generally a new star, like Nova Aquilæ (3), which suddenly appeared to us in 1918, increases its temperature to such an extent as, perhaps in twenty-four hours or even less, to shine a million times more brightly than usual. It is true that the sun is a star, but we may be thankful it has hitherto shown no signs of being a star of this kind. The oceans would evaporate, the forests would be in cinders, and life be destroyed.

After such an outburst a new star cools down and fades, fast at first and then slower, much as a red-hot poker cools. It takes years to return to its original brightness.

This normal procedure in the outburst of a nova has been attributed by some to gas-friction, when a star in its movement traverses

a nebula (whether bright or dark does not matter), just as a meteor shines by friction with our atmosphere. This theory may be quite wrong, but still it explains some of the facts better than any other theory.

The normal procedure may happen when a star penetrates a small nebula in twenty-four hours or so and then loses its heat according to the ordinary law of cooling. If, however, the nebula be an extended one, with patches of denser stuff, this would pretty well account for all known departures from the normal procedure ; the occasional increase of light during the descent ; and the proven fact that many a star, before and after its outburst as a nova, is a variable star, shining with more or less heat as it traverses outliers of the nebula.

Irregular Variables.—When the nebula is so extended that the star is never quite free from its resistance, then the star, in passing through strata or patches of denser gas, may exhibit to us a life-history of irregular spasmodic changes of brightness. Stars of this sort, whose outbursts are not so violent as that of a nova, are spoken of as "irregular variables," and most of them lie in regions where nebulæ are bright and visible. The most marvellous of all can be seen by people in the Southern Hemisphere, and is called Eta Argûs or Eta Carinæ by different astronomers. At present a telescope is needed to find it, because it has not been shining brightly for a great many years. But those who have a telescope can see it beautifully situated in the middle of a wonderful cloud-spot or nebula, which is spread out into a map of strange forms of glowing gas. They can watch, from year to year, its varying brightness, and recall that it was a fourth-magnitude star in Halley's time—1677—and of the second magnitude a century later. Sir John Herschel, at the Cape, in 1837, saw it suddenly brighten, almost like a nova, threefold, and get still brighter for two weeks ; then fainter, until again, in 1843, it burst forth almost equal to Sirius, the brightest star in the sky. Such behaviour is truly astonishing. Heat arising from friction in passing through a nebula might be the cause.

If we had been quite sure that new stars owe their light to the friction of a star passing through a nebula, then we might be pretty sure that, for centuries, this star Eta Argûs has been entangled in

some of the dense concentrations of the "keyhole nebula," with which it seems in the telescope to be associated. Thus novæ and irregular variables would be ascribed to the same cause. This conclusion would be confirmed by what has been discovered by help of the spectroscope. For Eta Argûs and new stars exhibit a very peculiar spectrum, the same in each case, implying a very exceptional and similar constitution.

There are many of these irregular variables, without any regular period from one maximum to the next, such as is shown by other types of variable stars. So much do they resemble novæ that it is sometimes difficult to say whether a star that has brightened suddenly is a nova or an irregular variable.

But we must remember that this gaseous-friction explanation of the brightening of some stars is only a hypothesis, and that, hitherto, it has not accounted for some of the facts about novæ. And all mere hypotheses must be looked upon with the greatest suspicion by every true astronomer.

A meteor one hundred miles up in our atmosphere, where the air is at least a million times less dense than at the sea-level, experiences resistance enough to heat it up in a second of time to incandescence, though it be travelling at only twenty miles a second. A star travelling, as some new stars seem to do, at over fifty times that speed would meet a resistance two thousand five hundred times as great in the same attenuated atmosphere. After acting thus for twenty-four hours, instead of a second or two as with meteors, a terrific heat would be generated. But we do not know the density of the gaseous nebulæ, so we cannot draw positive conclusions about the heat generated in the case of a nova.

III

Long-Period Variables.—The class of variables that next comes before us is perhaps the most interesting. It is one to which brotherhoods of amateur astronomers devote themselves with splendid energy in several countries scattered over the world. And at the same time the finest spectroscopes in the world are engaged upon this class of variables. This class includes all the fluctuating stars that were first discovered centuries ago, except Algol. It is

remarkable that, as a rule, any star of this class can be immediately detected as a variable by its spectrum.

We all know now that, broadly speaking, there are four separate classes of spectra exhibited by different stars. In one class hydrogen is most conspicuous ; in another, calcium and the metals ; in the third class, titanium oxide ; and in the fourth class carbon compounds predominate.

The long-period variables now claiming our attention are, all of them, of the third class, showing titanium oxide. Moreover, this class has a subdivision ; for a considerable number of these titanium-oxide stars show also *bright* hydrogen lines in their spectrum, in addition to the usual dark lines of star-spectra. The astonishing thing is that every star of this sub-class is a long-period variable star. Some people call Secchi's third-class " M-stars," and the sub-class—that containing glowing hydrogen—they call " Md." Every Md-star, without exception, is a long-period variable, and eighty-five per cent. of the long-period variables are Md-stars. If astronomers ever discover the true reason for this surprising fact they will then understand why these stars vary in brightness, and also perhaps the meaning of glowing hydrogen being shown in the spectrum of any other star.

These long-period variables have a period, between their times of maximum brightness, varying from eighty to five or six hundred days. The usual period is about a year. All other variables that are not irregular have periods of a few days, or less than a day.

The stars that were first found to be variable were generally long-period Md-stars. By far the best specimen was discovered by Fabricius, in 1516—Omicron, in the constellation Cetus, the Whale. It is generally spoken of as Mira Ceti (" The Wonderful "). It is near the celestial equator, a good deal to the right of Orion to us in the Northern Hemisphere, and rising three hours earlier. It is generally invisible to the naked eye, but is bright for three months in the year, and sometimes rivals Aldebaran. Its date of maximum cannot be exactly foretold, nor can the maximum and minimum brightness. Betelgeuse in Orion is another striking example of fluctuations like those of Mira Ceti.

The behaviour of Mira Ceti is typical of the whole class, of which three hundred and sixty-three members had been discovered

by 1911. Only fifteen of these are ever visible to the naked eye. Many of the enthusiasts who possess even small telescopes are now engaged in estimating their brightness, on every clear night, through all their changes.

Meanwhile the astronomers who use the greatest telescopes in the world have been examining the spectra of these stars. One of their most remarkable results, certified by all of them, is that there must be two bodies shining. For the glowing hydrogen, giving bright spectrum lines, is approaching us, compared with the mass showing dark lines, with the dark bands of titanium oxide, on a continuous bright spectrum. The velocity is about thirteen miles a second. The glowing hydrogen is intensified at maximum, just as in a nova. There are new spectroscopic discoveries being made every year about these wonderful stars. One of these variable stars in Aquarius, the Water-bearer, has certain bright lines in its spectrum, which prove the presence not only of glowing hydrogen, but also of glowing "nebulium," a constituent of nebulæ, but unknown hitherto in the sun, the stars or our own planet. Quite lately a photograph of this star disclosed a nebula round it.

IV

Short-Period Variables.—These take us out of uncertain speculation into a region of comparative certainty, because one of the two classes into which short-period variables are divided is caused by eclipses, when a bright and a dark star revolve round each other. These are generally called "Algol variables," because a variability of this kind can be easily noticed in the case of the bright second-magnitude star called Algol, or Beta of Perseus. In Perseus we see a string of stars between Cassiopeia and the Pleiades; Algol is just to the right of that string of stars. It really consists of two stars, one bright, the other dark; and every three days the bright star of the pair is eclipsed by the dark one, which is about equal to it in size, and its brightness is reduced to one-quarter. The whole eclipse is begun and ended in a few hours, and is repeated after nearly three days with the utmost regularity. This class of variable was described in Chapter X. Astronomers are able, from the observer's measures of the brightness in different phases, to deduce

very complete information about the orbit and dimensions of the two stars.

There is still one more type of variable star, one more puzzle for astronomers. It, too, has a short period. If, when looking up at the W-shaped constellation Cassiopeia, on a clear night, we examine the stars visible between that constellation and Vega, the first small star to catch the eye is Delta, in the constellation Cepheus. This star is representative of a large class of short-period variable stars. Its greatest brightness is a little less than third magnitude, which it attains at intervals of five days eight hours. Its brightness then falls off by one magnitude, gradually during four days, after which it rises, rather suddenly, to full brightness. In this performance it is quite regular, and it keeps as perfect time as any Algol variable. But it differs from them in the want of symmetry between the rising and the falling brightness. The "Delta Cephei variables" have a variable velocity to and from us in the same period as the light, as have the Algol variables. The spectroscope tells us this. But there is an important difference. Algol approaches us most between maximum and minimum, a necessary consequence of its orbit causing an eclipse. But Delta Cephei, on the contrary, does so when the star is brightest. These two differences of behaviour make the eclipse explanation, which succeeds with Algol, utterly useless with Delta Cephei.

There is a large number of these puzzling Delta Cephei variables, and they are found mostly in the Milky Way, which is another puzzle. Altogether the tricks and performances of all classes of variables are like those of a clever conjurer whose marvels we try to explain. And although guesses in plenty have been hazarded, there has not yet appeared any satisfactory explanation except in the case of eclipsing variables like Algol.

Perhaps the most wonderful of these conjuring tricks are those performed in certain globular clusters of stars, where Delta Cephei variables are found in swarms. The clusters are complete museums, full of those extraordinary performers among the stars.

At the beginning of this century Bailey took a large telescope to the Southern Hemisphere and watched the innumerable minute stars in that marvellous globular cluster Omega of the Centaur. When he announced the result the whole astronomical world was

astounded. It was not merely that in this small portion of the sky, one thirty-thousandth of the whole sky, he discovered nearly as many variable stars as all those previously known ; but he was able to tell us that their periods, between times of greatest brightness, were all very much the same—for the most part only about half-a-day.

We have been puzzled at the erratic behaviour of new stars and irregular variables. We have been puzzled by the yearly outbursts of long-period variables, and by their minor irregularities ; also by the glowing hydrogen gas by which long-period variables are accompanied, and the huge difference in velocity between the star and its glowing hydrogen. We have been puzzled by the Delta Cephei, short-period variables, their sudden brightening and gradual fading, and their diminishing velocity from maximum to minimum brightness. Here was enough to set us guessing and speculating. But what are we to say about closely packed clusters of stars (for Omega of the Centaur is not alone among clusters in this respect) in which hundreds of stars, varying in brightness after the manner of Delta of Cepheus, all perform their extraordinary conjuring trick of brightening and fading in the same interval of time, a fraction of a day.

We can only wait in hope of further light, humbly confessing that, up to the present, man's speculations, though based upon the highest knowledge yet attained about the forces of nature, are mere gropings and guesses concerning those astounding phenomena, the brightening and fading of variable stars. This is a humiliating position, but it acts like a great incentive to all true star-lovers to accumulate all kinds of observations that ere long may be expected to unravel these mysteries.

CHAPTER XIII

FLOWING STREAMS OF STARS

I

THE three stars in the tail of the Great Bear make a curve. By following the line of that curve the eye is arrested by a great star of the first magnitude. This is Arcturus, in Boötes the Herdsman. If the eye be carried along the curved line, as far again beyond Arcturus, it may be caught by another bright star much nearer to the southern horizon. This is Spica of the Virgin. The straight line in which lie the two stars at the end of the Bear's tail does not point directly to Arcturus. It passes between that brilliant solitary sentinel and a pleasing bright ring of smaller stars that form the constellation appropriately called *Corona Borealis.*

These hints about recognizing the stars in that part of the heavens are worth remembering, if only for the sake of star-friendship. They are put forward at this moment to help the reader to find Arcturus any summer evening. It catches the eye as the only important, and a rather solitary, individual in that part of the sky. For many reasons Arcturus is splendidly interesting, and there are many of us to whom this bright orange star is a friend always associated with one of the most fascinating realms of discovery in the heavens. This is a study of the "proper-motions" of the stars over the sky; very minute motions, but continuous and uniform. They are generally so minute as to escape observation except by the finest instruments, and most stars require years to show accurately the rate at which they move.

Arcturus was the first star which was found to be in motion. Stars had always been distinguished from planets by being called fixed stars until 1718, when Edmund Halley, the friend of Newton, compared the places of stars observed by himself with their places in the catalogues of Tycho Brahe, more than a hundred years before, and of Hipparchus or Ptolemy, eighteen hundred years before. He found that from the time of Hipparchus this star Arcturus had moved over a space twice the diameter of the moon—that is to say, it travels in the sky, among the other stars, at the rate of two seconds of arc every year. In the same period (eighteen hundred

years) he found that Sirius had passed over a space of one and a half diameters of the moon.

Few very bright stars are comparable in "proper-motion" with these two, Arcturus and Sirius. Alpha Centauri, however, moves quicker even than they, and Vega, too, has a high speed. Some smaller stars travel still quicker. One goes four times, another five times, faster than Arcturus; and the last of these would cover a space of the moon's diameter in a hundred and eighty years. But the proper-motion of most stars cannot be exactly measured, even with the most precise instruments, except by observations at long intervals of time; and many would require centuries or longer. So that it has become a convenient practice to measure the proper-motion of stars by the space that would be passed over in a century instead of a year.

Of all stars which are visible in quite a large telescope (down to the fifteenth magnitude) there must be forty thousand whose proper-motion is at least fifteen seconds of arc in a century.

II

We already possess catalogues of thousands of stars with the amount of their annual proper-motion, and also their direction, where these have been measured. But a mere catalogue does not tell us much until we represent it in some way, to give to it a meaning. Its contents become quite interesting when they are transferred to a star-chart. Lay a piece of tracing paper over the chart and mark with a pencil-dot each star given in the catalogue. Also mark, by a line from the dot, the direction of the star's proper-motion. Then make the length of this line from the star equal to the amount of the star's proper-motion, on any scale we may have chosen—say an inch to represent a second of arc of annual proper-motion.

When this has been done, the picture presented by the little lines of proper-motion takes a new meaning. The directions of the lines that have been drawn do not appear to be altogether fortuitous. There are many signs of streams or flows of stars, and of groups of stars all with a common motion. And after looking at the tracing, the universe of stars acquires for us an entirely new

character. It is no longer a stationary structure. It has become a moving, flowing universe of interacting suns, some single, others binary and multiple suns, whirling through space, over prescribed orbits and recognizable tracks, all guided and governed, in all probability, by the same forces of gravitation, cohesion, elasticity, chemical action, heat and electricity, which we upon this little world can study in our homes.

Such a surprising and invigorating transformation and change of outlook, from a dry catalogue into a realistic living picture, stirs the heart of everyone who cares for the stars. But it does much more. It has stimulated, and continues to stimulate, the intellectual powers of our greatest men, of those to whom no greater happiness exists than that of advancing step by step towards knowing, in their full beauty and truth, the fundamental laws designed at the Creation for the working of our present universe, laws perfect in their drafting ; and (doubtless for a beautiful purpose) steadfast, true and unswerving in the unfailing certainty of their execution.

To-day the new world of truths revealed to us by a glance at a star-chart of proper-motion is occupying the minds of many mathematicians, astronomers and natural philosophers, all devoted to the exact sciences ; and the talents of all are being devoted to patient observations, experiments and calculations which may lead, in the course of ages, to as clear an understanding of the driftings of the countless stars as Kepler and Newton shed upon the planetary wanderings in our relatively contemptible little solar system.

It must not be supposed, from what has now been said, that the chart of stellar proper-motions exhibits throughout, and at a glance, any systematic flow of stars. On the contrary, the general aspect of the picture is confused. But the great fact remains that we become immediately certain that there are groups of stars following a common route. And the inference is irresistible that the confusion will disappear when its causes have been fathomed.

III

It is a source of gratification to most people when new facts brought to their knowledge are best exhibited by the very stars whose friendship they have already acquired. The Plough, in the

constellation Ursa Major, gives one of the best examples of a group of stars all having the same proper-motion (Fig. 17).

Five out of the seven bright stars that give an outline to the Plough can be seen, on our chart, to be all travelling in nearly the same direction. The slight differences almost disappear when we take account of perspective. Lately, when the spectroscope was

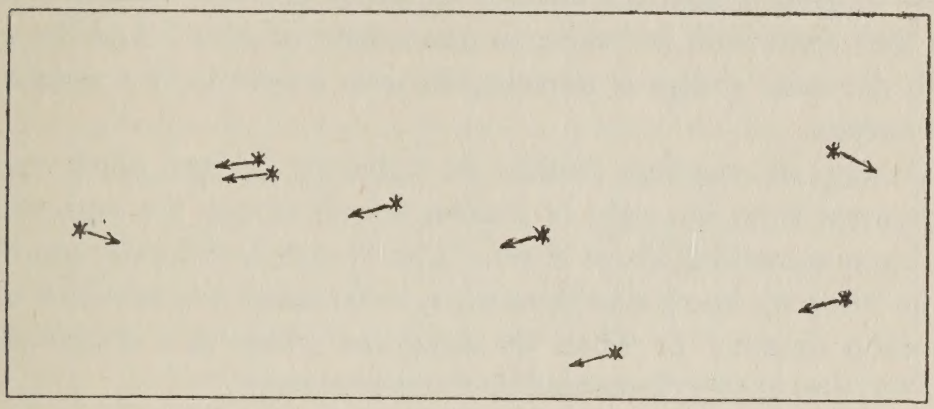

FIG. 17.—Stars in the Plough (*Ursa Major*), showing by arrows the directions and amounts of their Proper-Motions. All of these except two are moving with equal velocities in one direction

used for measuring the "radial-velocities" of these stars, to or from us, they were all found to be approaching us, and at not very different speeds.

In the end it has been clearly proven that all of these stars are travelling together at about the same speed, approaching us at an angle, and all of them flying parallel to a line drawn from our position to a place in the sky not very far from Altair, the bright star in Aquila, the Eagle.

If we know the distance of a star from us it is easy for a computer to find its exact motion in space from the observed proper-motion and radial-velocity. Unfortunately there are very few stars whose distance can be measured with sufficient accuracy for this purpose. One of these, however, is Sirius, the brightest star in the sky ; and the wonderful discovery has been made that its motion in space is from the same point of the sky—the "radiant-point" of the five Plough stars. Altogether, six stars in different constellations are suspected to be members of the Plough group, all going the same way, at about the same speed as the Plough stars. That Sirius, south of the equator, far away in space from the stars of the northern

Plough, should belong to the same group opens up a completely new conception of the stellar universe. This is true, also, when we consider that two stars of the Plough group are about twenty degrees apart, for this means that their distance from each other is seven times the distance from us of the nearest known star, Alpha Centauri. The distance of Sirius from Mizar in the Plough must be greater than the distance of either of them from us ; and yet they seem both to belong to one stream of stars. And the sun with the solar system is pursuing its own course in the middle of the stream.

During an evening ramble we certainly do get much more enjoyment from the sight of known friends among the stars when we know something about them. The Plough is still more pleasing to us when we know that these stars, so far apart, are members of a common stream ; or when we recognize Mizar as a double-star, and the first binary discovered by the spectroscope.

IV

Let us make another call upon a family of old friends among the stars, to hear about their travels. The region round that red star Aldebaran, king of the Bull constellation, can now be chosen to illustrate the existence of other star-streams. Everyone knows this star, to which the three stars of Orion's belt point. It is one of the lighthouses on the ecliptic, the trade-route of the planets. That route passes between Aldebaran and the lovely little cluster of stars called the Pleiades. Now these Pleiades, a bunch of six to most people, and of eleven to really good eyes, are a very wonderful group. When photographed with a very long exposure, each star is found to be enveloped in a haze of nebula, and nebular gas covers that region.

When the proper-motions of the six bright stars are looked at on the chart they all point in the same direction ; the six all seem to be moving as a family group together. At first this seems more to be expected in such a compact group than in the widely separated stars of the Plough, because the stars seem to be nearer together in the compact Pleiades. Yet it is quite likely that the actual distances between stars is about the same in both cases. In fact

this would be true if the Pleiades are about ten times farther away from us than the Plough. And this is not at all unlikely. Anyway, here we have a group of stars resembling those in the Plough by having a common motion among themselves. The telescope reveals two hundred and forty-six stars in the cluster between the

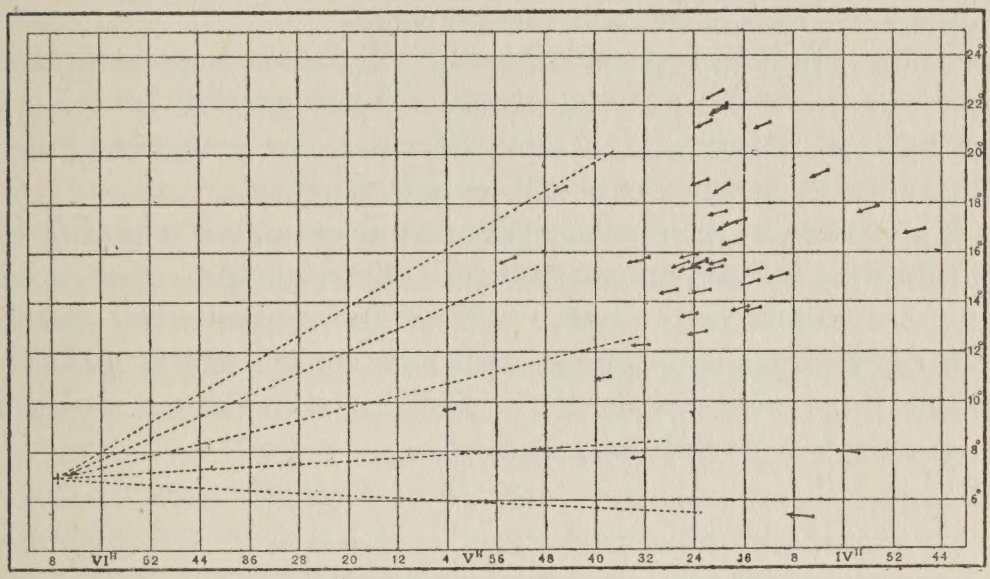

FIG. 18.—The Proper-Motions of Stars in the Hyades near Aldebaran, discovered by Boss

third and fifteenth magnitudes, all travelling much in the same direction, at the rate of about five and a half seconds per century.

In the same part of the sky there is a beautiful little string of stars, V-shaped, with Aldebaran at one end of the V, called the Hyades. Our pleasure in noticing them is very much intensified when we are aware that about forty of them, mostly telescopic, make up the most wonderful family of stars as yet discovered, all streaming at the same pace in one direction. So accurately are they doing this that the effects of perspective are quite marked when we plot them, with their proper-motions, on a large-scale star-chart (Fig. 18).

Perspective is well shown when we stand at an angle, and close to a large number of telegraph wires on poles, and make a sketch of them. The wires all seem to be directed towards one point in the distance, and would so be drawn in a picture of them. But the top wires would seem to point more downwards, and the bottom wires more upwards, than the middle wires. Now, if these wires

represent the paths of the Hyades stars, all moving at the same speed, we might paint with whitewash a length of one foot of each wire, some pretty near to us, others farther away. These white lines would illustrate the proper-motions marked upon our star-chart. Some would be inclined to the others. Some would appear by perspective to be shorter than others, while really all are going at the same pace to the same distant point.

These effects of perspective are all shown with surprising exactness in the Hyades star-stream. When checked by using a spectroscope for measuring their velocities, the accuracy of this illustration by perspective is still more convincing.

These stars, at their present distances from us, are ranked as of the third to the seventh magnitude. In the distant future, after sixty-five million years elapse, Professor Boss computes this cluster, now fifteen degrees in diameter, will have condensed into a cluster not over one-third of a degree in diameter, with the stars reduced to the ninth to twelfth magnitude.

V

Of course these motions that we observe are not absolute motions, but only relative to the position of our solar system in space; and the sun, with its attendant planets, must in all probability be moving through space like all the other stars.

Soon after a small number of stellar proper-motions had been measured, in different parts of the sky, a general tendency was evident for their apparent courses to radiate or diverge from a spot in the region of Vega (Alpha Lyræ) or the neighbouring constellation, Hercules. This fact is now quite established. Then it was obvious that this general tendency might be caused by a motion of our solar system in the opposite direction—that is, towards Vega. Just as, when we are slowly drifting in a boat through a stationary fishing-fleet, we may be unconscious of our own movement, and forget that we are not at rest. Then the fishing-boats all have an *apparent* motion in the opposite direction to that in which we ourselves are really going. If we be moving one yard a second to the north, each of the boats would seem to be moving one yard a second to the south, and its bearing, as shown by the compass, would

change more or less, except in the case of boats due north or south of us ; and the bearing of those to east or west of us would change the most, and, of these, the nearest would change place more than the more distant ones.

It is all a question of *relative* motion, and, in the case of the stars, *absolute* motion cannot be measured. If we happened to know from observation that the apparent motion of all stars was accounted for by a uniform speed of all of them in the same direction, as in the case of the fishing-boats, it would then be more convenient to speak of it as being due to a solar motion among the stars, rather than a stellar motion past the sun and planets.

The facts, however, are not so simple ; for each star has its own individual motion in addition to that attributed to our own motion among the stars.

When drifting northwards through the stationary fishing-fleet, boats to east or west of us seem to be going to a more southerly position. But if some boats are themselves moving to north, east, south or west, this rule is, in their case, disturbed. Supposing, however, that these individual motions are all at random, as many moving in any one direction as in the opposite direction, then an average of them all will cancel these random motions, and will certainly inform us that, on the whole, we are moving, relatively to the boats, towards the north, at one yard a second, or whatever our pace may be.

So also with the stars. If we want to find our own motion relatively to them we must take an average for groups of many stars in each direction of the sky. This average is used as having the individual proper-motion cancelled and as being entirely due to our own velocity relatively to that group of stars. This is what astronomers have done for all the stars that are near enough to us to show a measurable proper-motion. The great majority of stars are too far away for this. But the motion of our solar system among those stars near enough to us for accurate measurement has been computed by different astronomers, each using his own choice of stars, and each getting a slightly different result, but with a general agreement as to the direction in which the solar system moves. This direction in which we move among the nearer stars points towards the constellation Hercules, close to our old friend Vega.

This is the first great generalization reached by the astronomers about the stellar movements.

The marvellous power of the spectroscope in telling us the speed with which any star is approaching or receding from us has also been applied to get the solar motion by several computers, the present writer being one of them. The result has always been to show that most of the stars in the direction of Vega are approaching us, while at the opposite part of the sky they recede. This quite confirms the result derived from proper-motions. The spectroscopic method has this advantage, that it tells us the actual velocity of the sun's motion among the stars. It is about fourteen miles a second—that is to say, quicker than our earth moves round the sun.

VI

After this great conclusion had been established a new question arose : Are the individual motions of these nearest stars showing proper-motion entirely at random, or do the stars drift, wholesale, in swarms ?

For a hundred and fifty years astronomers, in dealing with the apparent proper-motions of the stars, were completely absorbed in their efforts to improve our knowledge of the exact direction in which the sun seems to be moving among them. So they never made an attempt to find out whether the individual motions of the stars themselves were all haphazard or bound by some system. It was only in the present century that the wonderful discovery was made by Professor Kapteyn of Holland, the friend and associate, in great astronomical researches, of our greatest practical astronomer, the late Sir David Gill.

Kapteyn found that the proper-motions of stars in different parts of the sky are not accounted for by a solar motion alone. Nor are they accounted for by a solar motion in one direction, combined with a general streaming of the stars themselves in any one direction. But they are extremely well explained by a solar motion in one direction combined with a general streaming of the stars *in two exactly opposite directions*, inclined at forty-six degrees to the solar motion.

This two-stream theory of stellar motion is one of the grandest

generalizations ever made in stellar astronomy. It was, however, entirely derived from studying the proper-motions of stars near enough to us for exact measurement, and need not apply to the whole universe of stars.

The announcement of this discovery was startling in itself, but it has puzzled astronomers to see how it can fit in with any probable system of movements subject to the laws of gravitation. That all the stars within range of our measurements consist of two mingled streams, moving in opposite directions, is simple enough as a geometrical fact. But when we seek to know by what process, or out of what previous condition, this commingling has arisen, the astronomer must remain baffled until new facts of observation give to him the clue for, perhaps, a still greater simplicity.

What a new outlook have these studies of proper-motion given to us upon the stars above ! No longer can we talk of fixed stars. All are in movement. Some, like Arcturus, seem to be pursuing a lonely course. Others, like Sirius, are, for some reason, travelling in company. We have the whole Plough group in Ursa Major, the Pleiades group and the Hyades group in Taurus, the Bull. And many others have already been detected. Overwhelming these are apparently two great swarms, commingled but moving in opposite directions, that include nearly all the available stars. And lastly, our own sun is travelling, so far as we now know, on its lonely course, like Arcturus and many others. Every night that we look upon the stars we can now in imagination regard them, as we do the great flakes of snow in a storm, whirled and drifted by currents of wind. Then we begin to envy the outlook of those who will take our place centuries hence, when these whirling, drifting movements shall have been assigned their place in the great scheme of universal gravitation.

Before, however, this vision of the flowing star-streams may be attained, our imagination must have eyes that can grasp billions of centuries in a flash. To us mere mortals the drifting snowflakes give place to a more solemn and more ordered progression. The flowing star-streams disclose to us only the local tactics that govern those battalions of the starry hosts whose movements our eyes can see and measure. We are able to pick out the

isolated patrols, the flying squadrons, the light skirmishers and the lumbering columns. They all have their place in the concerted and more general onward movement. The units may be large or small, slow or fast, and they shine in uniforms of white or gold, of orange or scarlet. Yet everywhere the strategical advance by the various corps of the Grand Army—brilliant, though silent and almost imperceptible—pursues its organized progress under a relentless persistency and discipline ; and ensures, for all of them, the continuous development of their infinite and eternal destiny.

CHAPTER XIV

CLOUD-SPOTS AMONG THE STARS

I

AFTER we have made friends of the stars and the planets they become real companions to us in a night walk. And still we are not satisfied. An irrepressible wondering as to what there is beyond our vision seizes each of us. We long to see deeper into the heavens, and to pick out any new things that a telescope can show. Giant telescopes may be beyond us, but the smallest spy-glass or binocular would be welcome at this stage.

With the help of such a plaything we can detect the phases of Venus, the moons of Jupiter, perhaps the rings of Saturn. The features of the moon, under different conditions of illumination during the month, are, by its aid, changed from a flat picture to a solid mountainous globe. The first glance with a small glass at the star-clouds of Sagittarius, the Archer, or Cygnus, the Swan, converts the plain white surface of the Milky Way into a new and crowded universe of small stars. Between the head of Perseus and Cassiopeia two lovely clusters of stars surprise us with their beauty. Here and there we pick up a double-star, of double colour, like a pair of sparkling jewels. The first taste thus acquired of the pleasures of exploring whets the appetite, and from such a beginning the birth of many an astronomer may be reckoned.

And so our exploration may go on. With the help of a telescope we may add to the *number* of our friends : more stars, more planets, more satellites, more comets—and more detail in most of these. But there is only one type of object revealed by the telescope that is entirely different from anything we see with the naked eye. These are certain minute, shining, cloud-like spots among the stars, called "nebulæ." It is perhaps too much to say that they can be seen only with a telescope. One or two are just visible to the naked eye. They have always been a puzzle to astronomers. And with the increase of power given by newer and larger telescopes an immense number of facts have been accumulated as to their numbers and distribution, their shapes, sizes and constitution, their internal motions, and their paths among the stars. At the same time, with

this increase of knowledge, they are, perhaps, more puzzling than ever, and far-reaching speculation has been brought to bear upon their relationship to the rest of the universe.

One of the greatest boons conferred by the telescope is that the increased power of vision not only adds to the number of stars, but introduces to us a totally new class of objects, not incomparable in number to the stars, exhibiting structural details such as stars cannot show, and forms suggestive of internal commotions like the whirlwind or the volcanic cloud.

When first discovered, these wonderful cloud-spots seemed all to belong to a single class, and to be nothing more than minute shining clouds, from which their name "nebulæ" was derived. And so few were then known that they were treated as curiosities. In 1771 Messier observed and numbered one hundred and three of the most prominent nebulæ. His catalogue is still used for their identification. Thus Messier 13, or M. 13, is a remarkable cloud-spot in Hercules. The *New General Catalogue* (*N.G.C.*) is much more complete. The great Andromeda nebula is called M. 31, or *N.G.C.* 224. So with others. Sir William Herschel's large telescope increased the number to over two thousand five hundred, and more powerful telescopes have added to the list. Finally, the prolonged exposure of a photographic plate is found to disclose a multitude of these minute cloud-spots all over the sky; and the latest estimate of their number is nearly a million. In one small piece of the sky, not much larger than the surface of the moon, no less than two hundred and forty-nine minute nebulæ have been photographed by the great telescope of the Lick Observatory.

But the increase in size of telescopes has brought to us news about these nebulæ far more exciting than their mere numbers. In 1848 Lord Rosse eclipsed all previous efforts by making, erecting, and using in Ireland his great 72-inch reflecting telescope, at a cost of twelve thousand pounds. He then set to work on the nebulæ. He added to their number, but his greatest contribution to astronomy was in the careful drawings he made of their shapes.

In the case of very many he was able to resolve the shining cloud into aggregations of minute stars, sometimes into globular clusters, but more often into star-groups, or strings, of various shapes, many of these demanding a still greater telescopic power for entirely

resolving the mass of light into discrete stars. His greatest discovery was that a very large number of these nebulæ show a spiral form in the strings of stars and wisps of glowing unresolved light. Later researches, with even more powerful telescopes, assisted by photography, have resolved more and more of the nebulæ into spirals, until to-day that form is generally attributed to the great majority of nebulæ, even when the form cannot be detected in the feeble or minute delineation.

Let us pass now from globular clusters and spiral nebulæ, in all of which there is evidence that possibly, by the use of higher and higher optical powers, their glowing masses will be the more completely resolved into their thousands of constituent stars. The next class of cloud-spots that excite our interest are very different. These are generally round, like the globular clusters, but differ from them in three respects. They cannot be resolved into stars. Their light is not concentrated at the centre, as when we look at a globe full of points of light. And in colour they differ from the clusters, being of a bluish green, milky tint. These pale glowing discs are called "planetary nebulæ," because they generally resemble a planet more than a star. Some are in the form of a ring. They can never be resolved into star-clusters. But there is a remarkable feature possessed by nearly all of them. In the centre of each planetary nebula there is a faint star. Moreover, this faint star always has a peculiar spectrum, which is very significant, and to which attention must be paid. It is what is called a *Wolf-Rayet* star.

Besides all these kinds of nebula that have been named there are irregular patches of brightness ; and, again, vast regions of the sky, covering a whole constellation or more, where the stars are found to be bedded in a sea of nebulous gas. There are also dark nebulæ, not hot enough to shine, hiding the stars that lie behind them.

The numbers, the diversity and the structure of the nebulæ call for the exercise of the keenest eyesight and intellect to discover all about them, and the place they occupy in the architecture of the heavens, and in the slow but sure development of events during billions of years.

II

After this general survey of what he is to expect, the star-lover is not likely to delay much before going out at night to get a naked-eye glimpse of one or two of these objects, armed, it may be, with a binocular. Any night when our old friend Vega is high in the sky is a good occasion to look for one of the finest globular clusters —Messier 13, in Hercules. This is close to the ring of stars called Corona Borealis [the plough-shaft, or the tail of the Great Bear, nearly points to Corona]. The cluster, M. 13, is about the same distance from the Pole-star as Vega, and close to Corona. It is the finest object of its class that is visible in our latitudes. It is visible as a mere cloud-point without a telescope, and remains structureless even in a 4-inch or 5-inch telescope with a high power. But, when seen through a really large telescope, it looks like a swarm of bees, or one of the globular clusters of gnats or midges to be seen of a summer evening on the banks of any Scottish river.

As a good many readers of these pages live perhaps in Australia, New Zealand, South Africa or South America, and can never see M. 13, their attention would naturally be given to one or other of the many globular clusters that are visible from southern latitudes. One of these, called ξ, in the constellation Tucana, is close to the smaller Magellanic Cloud, which is always conspicuous, and never sets in those latitudes. But the most interesting of all, in many ways, is Omega in the Centaur, easily visible to the naked eye as a hazy spot shining with the light of a fifth-magnitude star. This is a marvellous globular cluster, and contains, among many curiosities, hundreds of variable stars that brighten and fade once a day, or thereabout ; not all together, but with the utmost regularity. These globular clusters, like any swarm of insects, are all strongly congested at the middle of the space they cover (Plate XII.).

The autumn or early winter evenings are suitable for a good look at the constellation Andromeda. It is easily recognized by the line of three stars (Alpha, Beta, Gamma of Andromeda) that in northern latitudes are seen to start from the left top corner of the great Square of Pegasus, and run to the left towards Perseus. Here may be easily seen, without the help of a telescope, a faint object, which is really the largest and brightest of these wonderful nebulæ

[*Photographed at Victoria, B.C.*

PLATE XII.—STAR-CLUSTER IN HERCULES (M 13)

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that assume the spiral form. To find it, look at Gamma, the left star of the three, and Beta, the middle one. Notice the length of the line joining them. At half this distance from Beta, in a direction at right angles to the line of three stars, a careful search will soon find a small, hazy, comet-like spot. This is the great Andromeda nebula, M. 31. A small telescope fails to show the details of structure, but there are not many objects in the heavens more surprising or more suggestive than this spiral nebula when seen through a powerful telescope.

Let us now turn to Orion, who reaches his highest altitude in the sky five or six hours later than Andromeda, or at the same hour two or three months later. Everybody knows this splendid constellation, the most brilliant of all. Orion's sword-scabbard points to the Pole, and, in the middle of it, a close scrutiny seems to suggest a luminous haze without form. A very small telescope shows it as a clear, bright patch. This is the great Orion nebula, which is in many ways the greatest and most wonderful of all the nebulæ in the sky. Whether the nebula itself can ever be recognized with the naked eye is very doubtful, though there is something to be seen, more like the glow we sometimes get from a group of stars too small to be visible. But the astronomer who knows what wonders exist in this nebula is glad in his midnight walks to be able to recognize that slight indication of its presence.

With a small telescope other nebulæ of the same kind may be seen beside the three stars of Orion's belt. They are all part of one great extended nebula that is known to cover the whole constellation, and beyond.

III

Spiral Nebulæ. — Having now told of the most conspicuous nebulæ that are within our reach in the absence of a very large telescope, the next thing to do is to examine the wonderful shapes of the nebulæ through a very large telescope. But if every reader were to make this demand upon the six or eight very large telescopes of the world, the progress of discovery would receive a severe check. Fortunately there is a remedy arising out of the modern method of using these large telescopes.

The largest telescope in the empire, whose performances equal,

if they do not excel, in many particulars, all others, is the great reflector of seventy-two inches diameter in the splendid climate of Victoria, British Columbia. The only others comparable with it for certain purposes are the 60-inch and 100-inch reflectors at Mount Wilson, in California. The largest *refractors* are at the Lick Observatory in California and the Yerkes Observatory at Chicago.

Now the value of all these huge telescopes has been doubly enhanced by the art of photography. We are able, by prolonged exposure of a photographic plate in the focus of a telescope—not only from hour to hour, but again, with the same plate, from night to night—to record the existence and position of objects invisible to the human eye with the most powerful optical aid.

There is no department in astronomy in which the application of photography appeals to the lay mind more than in the marvellous pictures that have thus been produced of the shape and structure of the nebulæ. And this is the principal reason why, in these days, those who are interested in the heavens can follow the discoveries about these marvellous cloud-spots far better than in the days of Herschel or Lord Rosse. It is not every star-lover who can, like these great men, build for himself his own large telescope ; but he possesses one advantage. The huge telescope, denied to him, may have cost altogether a hundred thousand pounds before it could do its work. And yet, for a shilling or two, he can become the possessor of a print or a lantern-slide of any of these nebulæ, containing nearly all the details that can be detected by the astronomer himself who controls that priceless observatory. It is impossible by mere words to describe the surprise, wonder and awe which fill the mind of anyone when first brought face to face with these marvellous photographs. The *Publications of the Lick Observatory*, vol. viii. (1908) and vol. xiii. (1918) contain a great number of reproductions from photographs.

Herschel's telescope showed the finest spiral nebula as a single ring, one half of its contour surrounding a very bright globular nebula at its centre, and beyond the ring another small round nebula. Lord Rosse's great reflector disclosed a spiral structure in this nebula whose wisps of countless suns and nebulous stuff start from a central nucleus in spiral curves outwards. In the latest photographs details hitherto unseen are portrayed ; and we can,

PLATE XIII.—TWO SPIRAL NEBULÆ [*Both photographed at Mount Wilson*

(*Above*) The Whirlpool Nebula in Canes Ven. (*N.G.C.* 5194-5195), and (*below*) the Nebula (edge-on) in Coma Berenices (*N.G.C.* 4565)

in imagination, almost trace the course of events. Two great clusters of innumerable suns would seem to have collided indirectly and not centrally, and so they may have been sent spinning and drawing out their trains of stars into two united spirals. This is appropriately called the Whirlpool nebula, *N.G.C.* 5194-5195, and is the most striking example of all the spiral nebulæ. It is in the Hunting-Dogs, below the tail of the Great Bear. Others of a similar shape, and nearly as wonderful, are in the Virgin and the Great Bear. In shape they are like the strings of a mop when twirled round its handle ; or they look like the Catherine-wheels of a firework display (Plate XIII.).

All of them suggest motion, rotation, a force of attraction, and myriads of years as having combined to develop these marvellous structures. All this is at a distance from us so great that each one of them may be of enormous size, and may well comprise a duplicate of ourselves and our own complete stellar system and milky way.

The nebulæ are not uniformly scattered over the sky ; they are localized in many ways. The constellation Virgo contains hosts of these telescopic objects, while the opposite region of the celestial sphere is comparatively bare of them. All spiral nebulæ are not so placed as to be seen by us " full-face," like the Whirlpool nebula. The great Andromeda nebula presents a three-quarter-face portrait, and many are seen side-face or edge-on. In the photographs of these last we may see a luminous, bun-shaped, central glowing mass made up perhaps of stars, and its spiral ring is seen as a long band of light cutting through the central nucleus. Often along the middle of this band there is a black central line, showing up well against the bright parts. It reminds us of Saturn and his rings. This suggests that the outer regions of the spiral ring are neither luminous nor transparent, but made of cold, dust-like matter that is opaque (Plate XIII.).

Then, again, we see queer things happening. The spirals are supposed by some to be the milky way of each nebula. Now, in the milky way of the Andromeda nebula a great many " new stars " have been seen to burst forth, to shine for a time, and disappear, just as they do in our own Milky Way. Of course they are hundreds of thousands of times feebler, owing to their great distance from us.

No one can doubt, after inspecting the photographs of the spiral nebulæ, that these enormous masses, or independent universes, are in rotation, even before any confirmation is forthcoming. So we are not surprised to learn that, in the last few years, actual measurements of rotation have been made in several of them.

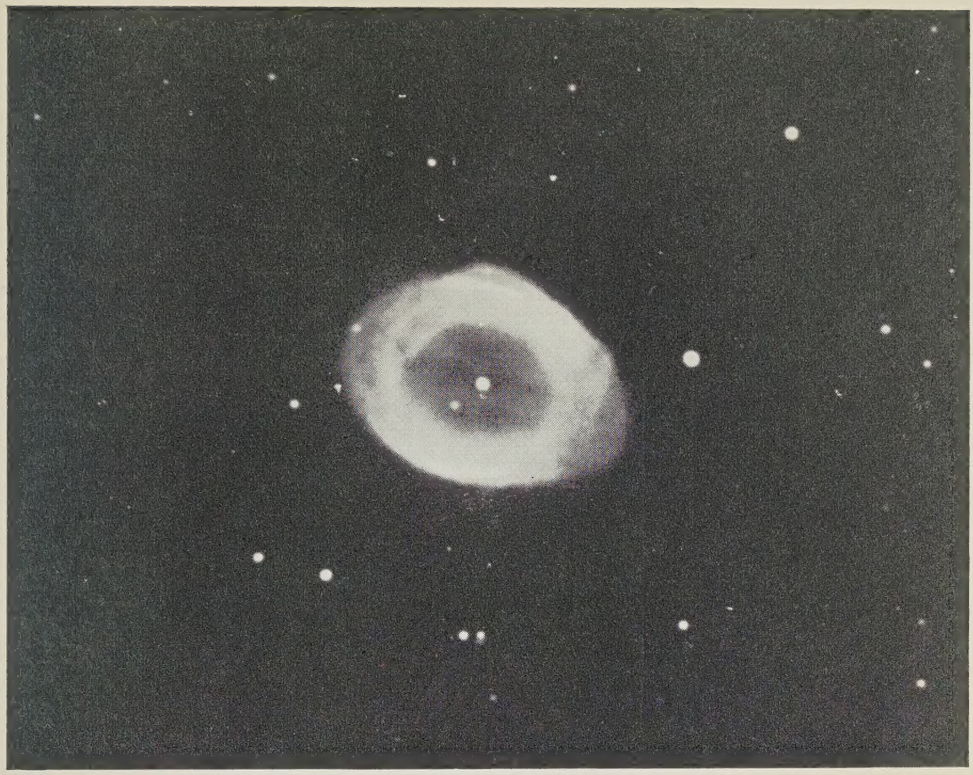
And, when passing from spirals to the globular clusters, if we reflect that the force of attraction between all particles of matter probably extends over all space, then the globular clusters do also suggest rotation to prevent their collapse by attraction to the centre of the cluster. We may hope some day to have these motions made visible by a comparison of photographs taken at intervals of many years or centuries.

IV

Planetary Nebulæ.—The photographs of nebulæ, whether of the cluster or the spiral form, open out to us new visions of infinity and eternity, developing under the same all-governing laws of force under which our everyday life is controlled. The photographs of "planetary" nebulæ now demand our attention. They add still more to our wonderment, for their variety of shape, their constitution, their movements, their position in space and their evident relationships to certain stars all seem to supply a basis for speculation of far-reaching character, although little can be claimed as being positive knowledge.

Most of them are nearly uniformly illuminated compact patches of light, generally round or oval. Some show a certain amount of structural detail. Some of them are ring-shaped, and the most famous of these is one in the Lyre, not far from Vega, about the apparent size of Jupiter. It is not black inside the ring, but faintly luminous, and, like nearly every planetary nebula, its centre is occupied by a star (Plate XIV.).

The term "planetary" ceased to be suitable after large telescopes were used to distinguish their features. Names were given to some from a fancied resemblance, which has often been dispelled by a larger telescope. One cloud-spot was found by Lord Rosse to resemble a crab. But now the Crab nebula is quite irregular in the photographs. The Owl no longer resembles that bird. The Keyhole, the Dumb-bell, and the Omega nebulæ no longer



[*Victoria, B.C., and Mount Wilson*

PLATE XIV.—PLANETARY NEBULÆ

(*Above*) Ring Nebula in Lyra, and (*below*) Owl Nebula in Ursa Major

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suggest these shapes. But there are features common to all of them. The central star is nearly always there. And their colour, pale greenish blue, is quite different from the white nebulæ, which include clusters and spirals.

The reason for this fundamental difference in colour between planetaries and white nebulæ is the great discovery made by Sir William Huggins on 29th August 1864. On that date, a few years only after the invention of the spectroscope, he pointed one of these instruments at a planetary nebula near the Pole in Draco. He was astonished ! For the first time in the world's history he knew that he was looking upon one of the lights of heaven that consisted of a glowing gas.

A prism is a wedge of glass. On looking at the sun through such a wedge it seems to be shifted to another place, and no longer looks like a round sun, but like a band of colour, the shift being different for each of the many colours of which white light is composed. So it is with a candle whose light comes from glowing carbon, not hot enough to be in the gaseous state. But light coming from a glowing gas is different. A spirit-lamp is hot, but not bright. When you put a pinch of salt into the flame, the sodium, of which salt is made, is vaporized, and it shines, a bright, yellow candle-flame. Seen through the glass wedge, or prism, this flame is certainly displaced, but only a single bright, yellow image of the flame is seen.

When Huggins looked through his prism at the planetary nebula in Draco he saw at first only a single image. It certainly was not drawn out into a band of colours ; and he knew, for certain, that planetary nebulæ are made of gas, whereas the spiral nebulæ are composed of condensed material, like the sun.

This was really a remarkable discovery. It was also puzzling, because if gas be put into a balloon it expands ; and although the gravitation of its particles does cause attraction, no doubt, yet the attraction is too feeble to overcome the expansion. It was natural to suppose that if a planetary nebula is made of gas it ought to expand and be dissipated, if gravity is not strong enough. The answer is that when passing from a quantity of gas the size of a balloon to a globe hundreds of millions of miles in diameter, the control of gravitation, attracting all the parts together, may predominate over the tendency to expand.

Now, in the last few years, the distances of some of the planetaries have actually been measured. This enables us to learn their diameters. These are enormous. If we take as our unit the distance from the earth to the sun, the diameter of the smallest planetary that has been measured is one thousand three hundred and fifty times the length of that unit, and the largest yet measured is ten thousand times the length of our unit. A sphere that would envelop the whole solar system would be only sixty of our units, a small fraction of the smallest planetary nebula in size.

Planetaries are not the only nebulæ that are made of gas. The brightest, and in many ways the most wonderful, nebula in the sky is the great Orion nebula, and, like all those classed as irregular, it is made of gas. In form it looks like a sun-lit thunder-cloud, torn by conflicting internal forces (spectrum on Plate XI.).

There are many other gaseous nebulæ easily found in Orion and the neighbouring constellations. And the whole of that region of the sky, when photographed with a wide-angle lens in a camera, is, after many hours' exposure, found to be aglow with nebulous light. The gases or vapours which we find to exist in these nebulæ are, in all cases, the same ; they are the lightest gases known upon the earth—hydrogen and helium. But, in addition, the spectrum declares still more emphatically the existence of a new chemical element, unknown upon this globe ; and to it has been appropriately given the name "nebulium."

Among the stars themselves helium is characteristic only of stars that are in limited groups in certain constellations in the Milky Way. Orion and the Ship are full of them. And it has been found that the gas in the great nebula of Orion, and in the cloud of gas which is spread over that constellation, as well as the more solid stars containing helium in that constellation, are all travelling together in space, in the same direction, and at the same velocity. They form a detached system.

Irregular nebulæ made of gas are found in other parts of the Milky Way ; and widespreading clouds of gas, like the one covering the constellation of Orion, have been discovered in the Bull, the Scorpion and Ophiuchus. But all gaseous nebulæ are strictly localized. They group themselves most decidedly in and close to the star-clouds of the Milky Way. The total number of visible

planetary nebulæ that have been discovered does not reach the modest figure of two hundred. But we have plenty of evidence of the existence of large numbers of invisible nebulæ, not hot enough to shine with their own light, and hiding all the stars that may be behind them, so as to look like black patches on the luminous background

Astronomers to-day are only groping for elementary facts about the movements of the starry and nebular hosts. That great instrument of research, the spectroscope, has been in their hands only about sixty years. Its revelations about stellar and nebular motions will some day, let us hope, supply us with laws as clear and simple as those which Kepler found for the solar system. A real astronomer cannot escape from the sense of humility in the vast extent of his ignorance. In stellar and nebular dynamics much, indeed, has been done ; but in this early century of the world's history we certainly cannot claim in this field to have passed with any certainty the stage that, in solar-system dynamics, was reached by the Babylonians.

One great generalization does stand out. The gaseous nebulæ are part of the Milky Way. The "white nebulæ"—that is, globular clusters and spirals—are not found in that region of the sky. The gaseous nebulæ ought to be looked upon as an important part of our own stellar universe, if we are to regard the spiral nebulæ as being independent isolated universes like our own one, separated from us and from each other by immeasurable volumes of blank, empty space. This is a hypothesis which is supported already by some significant facts ; and so long as we bear in mind that it is only a hypothesis, which can be discarded if necessary, it helps us to collect many astronomical facts into a consistent scheme.

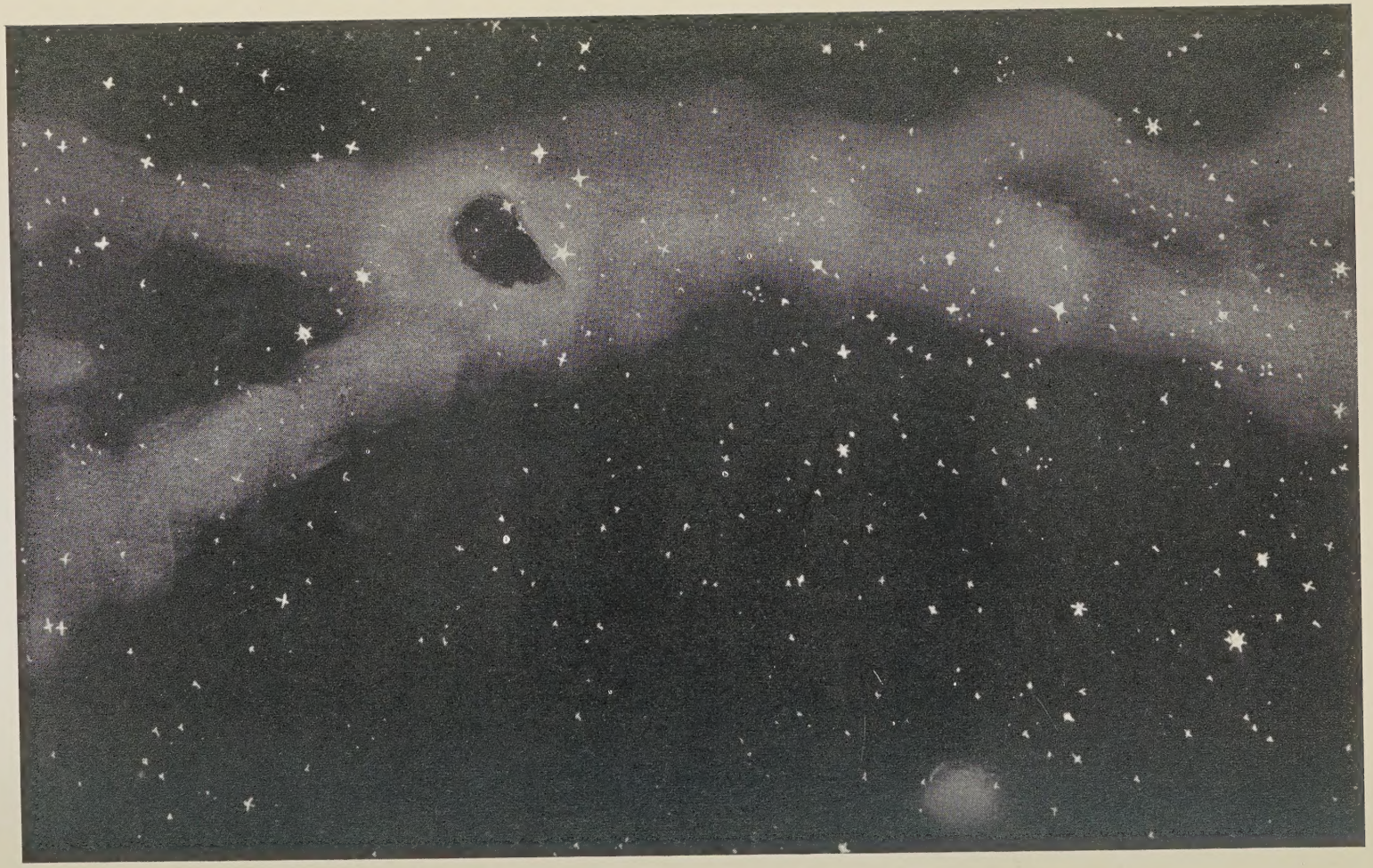
Thus we fit into such a hypothesis the new facts that come to our knowledge. It is something to know—as we are told by the spectroscope—that gaseous nebulæ in the Milky Way often travel with a velocity of forty or fifty miles a second, such as is reached by some stars. But from the same source of information we also learn that the spiral nebulæ attain velocities of nearly one thousand miles a second.

Then, again, as to their size or mass. In some of the planetary nebulæ whose distance is known the two opposite sides of the ball are found to have opposite velocities, one side coming towards us,

the other going from us. If, as seems right, we attribute this to rotation of the body of gas, the theory of gravitation tells us the actual weight, or rather mass, of the nebula compared with the sun. Already, in this way, preliminary estimates have been made of the masses of three planetary nebulæ. One is one hundred and sixty-two times as massive as the sun ; another is nineteen times. And the Ring nebula in Lyra is estimated as being nearly four times as massive as the sun.

Regarding the great spiral universes, we have not the same kind of exact measurement. All that may be said is that astronomers have, in the last few years, been much helped towards fruitful speculation and hypothesis by some of the ablest mathematical investigators of dynamical problems. Often these searchers after truth are able to tell what would be true if certain assumptions could be accepted. Now, one of the "probable truths" which have been reached in this way is that the mass of a spiral nebula is many thousand times that of the sun. In fact the Andromeda nebula would be of the same order of magnitude as the whole of our stellar universe, including all the occupants of the Milky Way. This, if true, gives strong support to the "island-universe" theory of spiral nebulæ. More recently, in 1925, Dr Jeans infers, from observations made by Hubble, at Mount Wilson, and others, that the nucleus of this nebula has a mass that is equal to two thousand five hundred million suns.

In conclusion, the important truth remains that the great and wonderful new class of objects revealed to us by the telescope, the white globular clusters and spiral nebulæ, along with the gaseous planetary, irregular and diffuse nebulæ, constitute a very important link, possibly even the key to our final understanding and interpretation of the structure of the universe.



Rift in Milky Way | α and β Centauri | Coal-sack | Southern Cross | Magellanic Cloud | Canopus

PLATE XV.—THE MILKY WAY IN SOUTHERN HEMISPHERE

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CHAPTER XV

THE MILKY WAY

I

On a very clear night in our latitudes attention is often drawn to the Galaxy, or Milky Way, with some wonder as to what is the meaning of that pale arch or band of light stretching across the sky from horizon to horizon. If any consider it to be without beauty or interest, they will be surprised to be told that, after becoming aware of its full significance, they will look upon it as the most wonderful and sublime and beautiful of all celestial phenomena. But so it is; and it has become more and more so since the discoveries by astronomers have disclosed its constitution, and its importance in the universe.

Only one half of the entire belt can be seen above the horizon at once, the other half being below, exactly opposite the visible half. Indeed there is a portion of it which can never be seen in our latitude, being so near the South Pole that it is always below our horizon. If the earth were annihilated, or made transparent, so that we could see the whole celestial sphere at once, the Milky Way would appear as a complete belt surrounding us.

Unfortunately for us, the hidden parts are the grandest and brightest. In southern latitudes the Milky Way does not look like a mere appanage of the starry firmament. It dominates everything, and often overwhelms the stars by its brilliance. There, too, our interest is increased by the gaps of blackness that disturb its continuity and puzzle our understanding. At the Southern Cross there is a pear-shaped vacancy so conspicuous and remarkable as to arrest the attention of the most careless gazer. It is called the "coal-sack." Its size is about eight by five degrees, and this jet-black vacancy, in the middle of one of the most brilliant patches, contains only one star visible without a telescope. Either the light of the Milky Way is there obscured by a black cloud among the stars, or else there is a hole going right through the Milky Way (Plate XV.).

Then, again, in the Southern Hemisphere we discover a great longitudinal black rift along the central line of the Milky Way; which is, in fact, thus divided, over a length of a hundred and fifty

degrees, into a main stream and a side branch. This rift starts at the bright pair of stars, Alpha and Beta Centauri, which point to the Southern Cross. The main stream and the partly interrupted branch then exhibit the very richest and most brilliant portion of the Galaxy, in passing the constellations Sagittarius, Scorpio, Ophiuchus and Aquila, to meet again in Cygnus, where the rift may be well seen in northern latitudes. From Cygnus the bright belt, no longer divided, continues to Cassiopeia, where it is only ten or fifteen degrees from the Pole. It then passes by Perseus, Taurus and Orion, west of Sirius, to the southern constellation Argo and the Southern Cross.

The great black rift is a source of wonder to everyone in the Southern Hemisphere. It is so surprising that often on board ship, when coming on deck after dinner and looking overhead, one sees the bright sky blotted out, as it seems, by the foul black smoke pouring out from the steamer's funnel and streaming away aft, although the ship is burning smokeless coal. It takes some minutes to realize that the sole cause of the illusion is the black rift in the glowing Milky Way.

There is still another reason why the southern hemisphere of the Milky Way is the more interesting. It is only there that the Magellanic Clouds can be seen, two glowing cloudlets like detached fragments of the Milky Way.

In those regions the Galaxy is resplendent. It no longer resembles a mere wash of white paint upon the celestial vault; it suggests an assemblage of luminous clouds, and may well give to the beholder a fancy that the Creator has taken great handfuls of universes, like snowballs made of myriads of stars, and has hurled them into the ring of light, there to spread out and encroach on one another; while some parts of the ring seem to have escaped the bombardment, leaving blank spaces; and two throws seem to have missed their aim entirely, and formed the Magellanic Clouds.

When Galileo was so fortunate as to be the first to point a telescope at the midnight sky, he could not fail, and did not fail, to make a great discovery every night. One of the most gratifying revelations granted to him was the discovery that the Milky Way is no continuous cloud of nebulous light, but consists of multitudes of minute stars too feeble to be seen individually without a telescope.

[*Photographed by Barnard*

PLATE XVI.—CLOUDS OF STARS IN THE MILKY WAY IN OPHIUCHUS

[*To face page* 175

And now, in the twentieth century, we are discovering that, in all our researches about distances, movements, sizes or constitution of the heavenly bodies, this Galactic plane, the central line of the Milky Way, is the fundamental basis for the construction of a comprehensive cosmogony, that shall enlighten us as to the construction, and as to the laws underlying, the movements of the whole material universe (Plate XVI.).

II

What is the form of the space which is filled with the stars of our Galaxy? This is a problem that has been puzzling the speculative section of astronomers, from the days of Sir William Herschel, the father of modern sidereal astronomy. And it is a pleasing fact that the huge mass of observations bearing on the Milky Way, accumulated during the present century, support the assertion made by that great man to the Royal Society in 1785. The heading of one of his sections was this : "We inhabit the planet of a star belonging to a compound nebula of the third form." Speaking of the Milky Way, he then said : "I shall now proceed to show that the stupendous sidereal system we inhabit—its existing stratum and its secondary branch, consisting of many millions of stars—is, in all probability, a detached nebula."

There is now little doubt that the space occupied by the stars of the Galaxy is in form like a ring surrounding us, filled with clouds of stars, and streams of stars, and nebulous gases. Also, that between us and the nearest part of that ring there is a more uniform distribution of stars in every direction in a spheroidal or bun-shaped space, within the ring. The massing of the stars in the direction of the median line of the Milky Way (the Galactic equator) is not due to crowding, but to the vast depth of the stratum. In higher Galactic latitudes there is probably a much more restricted distance within which stars may be found. The more we increase the power of our telescopes, the more faint stars do we find in the distant parts of the Milky Way. Or, as Newcomb has forcibly put it : "If we should blot out all the stars visible with a 12-inch telescope, we should find that the greater part of the remaining stars were in the Galaxy."

The question now is, "What would this ringed space of star-

clouds and the bun-shaped central spheroid look like if seen from the outside?" Before attempting an answer, we notice that the telescope, assisted by photography, shows many objects among the stars, that were called "nebulæ" when first discovered, from their cloud-like appearance. They were supposed to be masses of glowing gas. Increase of telescopic power partially resolved many of these, in Herschel's time, into star-clusters, some of them globular or oval-shaped and condensed at the centre, others disc-like and of uniform luminosity like a planet's disc of a milky colour, others quite irregular and apparently irresolvable. Herschel always maintained forcibly the view that the two last classes are gaseous, and are not resolvable into star-clusters.

After the late Lord Rosse had constructed the greatest telescope in the world, seventy-two inches in diameter, he used it for studying nebulæ. He discovered that with his great magnification a large number of them showed a spiral form, and many of those which had hitherto looked like clouds could be resolved, as Galileo had resolved the Milky Way, into countless groups and sprays of small stars. It then seemed probable that, with increased size of telescopes, all nebulæ would be resolvable into star-clusters.

This expectation was for ever dispelled, and Herschel's surmise proved correct, when, in 1866, Sir William Huggins directed the new instrument of research, the spectroscope, upon a planetary nebula in Draco, the Dragon, and later upon the great nebula in the sword of Orion. Seen through a spectroscope, the light from most nebulæ (the spiral ones) is spread, like the sun's light, into a continuous "spectrum," or ribbon of colours from red to violet. But the light from the Orion nebula showed only a very few definite colours. This wonderful discovery showed to those familiar with the spectroscope that the light came from glowing gas, and the first gas to be recognized by the colours emitted was hydrogen. Since then, helium has often been found in gaseous nebulæ, and also an element quite unknown among terrestrial substances, to which the name "nebulium" has been given. All of these gaseous nebulæ are in, or close to, the Milky Way or its branches.

But this is not all. Of late years astronomers have been convinced that in the Milky Way there are a great number of dark, non-luminous nebulæ which blot out the stars that lie behind them.

Ordinarily, the known gaseous nebulæ have been supposed to shine by virtue of their temperature or electrical excitation. When these are insufficient, the gaseous nebulæ are non-luminous. One of the most striking first-fruits of the gigantic 100-inch telescope, completed at Mount Wilson, California, in 1918, is a photograph of a nebula in the belt of Orion, a part of which is obscured by a well-defined dark nebula, like a black rock rising out of a luminous ocean.

Then photography has extended the Great Nebula in Orion's sword by showing fainter outlying parts enveloping most of that constellation and the sky round it. So also each star of the Pleiades and the Hyades are enveloped in similar nebulosity, as also other parts of the Milky Way.

The general result is that we now know the Milky Way to be the home of gaseous nebulæ, both bright and dark. The spiral nebulæ, on the other hand, are composed of clusters and sprays of stars, and give a spectrum like the stars, nearly continuous from red to violet. They show a distinct tendency to avoid the Milky Way.

Sir William Herschel, in 1785, surmised that the whole of our sidereal system is one example of the class now known as spiral nebulæ. These, when sufficiently magnified, have a shape something like the white foam you may see in the eddies of a swift river when it sweeps past a jutting-out rock ; or like the froth on a cup of coffee when stirred to give to it a circular motion. Radial star-spangled arms are often seen, of spiral form, issuing from a bun-shaped centre.

The modern view of the constitution of our sidereal system goes even farther than Herschel's surmise. It now seems more than probable that the whole of space is practically void of stars, except where the spiral nebulæ exist as "island universes" ; and that the whole of our sidereal system, with the Milky Way, is only one, and not the largest, of these countless spiral nebulæ revealed to us in the beautiful photographs by the gigantic reflecting telescopes of the present century, like our great 72-inch telescope at Victoria, British Columbia, or the 100-inch at Mount Wilson.

III

What types of stars do we find as the principal constituents of the Galaxy? The most important discovery about the constitution of the stars by the spectroscope was Father Secchi's classification of stellar spectra. It has been extended and subdivided, but it remains fundamental, basic.

Secchi found about half of the stars to be of one class and half of a second class. Type I. is like Sirius, the white stars, their spectra being due chiefly to the gas hydrogen, the lightest element, with the smallest atomic weight of all substances. Type II. is like the yellow Capella or our sun, their spectra being due chiefly to metals, including nearly every metal known on the earth, but not the heaviest ones. Types III. and IV. are smaller in number. Both are red stars : III. due largely to oxide of titanium, IV. to carbon compounds.

Taking the two principal types, I. and II., the second are distributed pretty uniformly over the sky, and certainly are predominant in the bun-shaped space that is inside the ring of the Milky Way. But Type I., hydrogen, are crowded into the Milky Way. Later research since Secchi's pioneer work made a separate section of some stars in Type I., those that contain helium, the second-lightest gas known on our globe. These not only frequent low Galactic latitudes, but are confined to certain longitudes also. The helium stars are among the most specially localized types of stars known.

These few facts, taken alone, might lead us to say that, if our sidereal system is a spiral nebula, with a central bun-shaped space like other nebulæ, then the central space is the seat of metallic elements, out of which stars of Type II. and the sun and earth have been made ; and the radial arms in our nebulæ are the seat of hydrogen, except one or perhaps two of the arms, which are helium. Such a supposition might at this stage be natural ; but astronomers of to-day generally favour a different interpretation of the diversity of spectral types.

There is another type of star favouring the Milky Way, distinguished not by their spectrum, but by the fact that they vary in brightness up and down in short periods of a few days. Excepting

the hydrogen stars of Type I., and these variable stars, all other kinds of stars that cling to the Milky Way are stars whose spectra show bright lines or bands instead of, or in addition to, the dark lines of the normal types. These are (1) Wolf-Rayet stars; (2) Secchi's Type I., with bright hydrogen lines added; (3) new stars; and (4), as already stated, gaseous nebulæ. It will be well to say a few words about each of these.

IV

Soon after the spectroscope was applied to astronomy, a class of stars began to be discovered having spectra quite different from any of Secchi's four types. They are called, from their discoverers, Wolf-Rayet stars. They can easily be recognized by the eye, even with a weak spectroscope, for the spectrum then seems to be all concentrated in two bright bands, one in the blue, the other in the yellow. With the increased power given by photography these and other wide bright bands are shown on a faint continuous spectrum.

Thus we learn that this type of stars are made of luminous gas, as are the nebulæ that haunt the Milky Way. Now there is no feature of local concentration in space more marked than the presence of all the known Wolf-Rayet stars (except some in the larger Magellanic Cloud) within a few degrees of the central line of the Milky Way. Their connection with planetary nebulæ having a star as a nucleus has lately been proved by the discovery that the nucleus star is always a Wolf-Rayet star.

The next type of stars with peculiar spectrum which haunt the Milky Way are stars of Secchi's first type, the hydrogen and helium stars, exactly like the others, except for the addition of *bright* hydrogen lines in their spectra.

Finally, all the new, or temporary, stars that suddenly burst forth into great brilliance, and slowly fade away, are, with one exception, found in the Milky Way, and generally in those longitudes where the gaseous nebulæ most do congregate.

Concerning these novæ, all that can be said at present is that their great brightness is largely due to glowing hydrogen gas, showing as bright bands superposed at first on one of the ordinary stellar

spectra; that the stellar spectrum grows faint and disappears; and that to the bright hydrogen lines are added later the bright lines of Wolf-Rayet stars; and that when all of these have gone, there remain generally only certain bright spectrum lines due to the unknown element "nebulium," which belong to nebular spectra, but to no known terrestrial substance.

It appears that all of the gases peculiar to occupants of the Milky Way are the lightest known gases—a curious and interesting result. And an equally important generalization is that all of the heavenly bodies that exhibit in their spectra the bright lines of hydrogen, helium, nebulium and nitrogen are very markedly localized in the Galaxy, while others that do not show bright lines, but which also frequent the Milky Way, have their spectra dominated by hydrogen and helium.

V

Such are the facts or data that astronomers are hoping to combine into a complete theory of the constitution of the Galaxy. We have to confess that up to this date none of the theories that have been suggested is sufficiently complete to explain all of the facts. There is, however, some satisfaction in finding that the work done by astronomers of late years has brought so many diverse problems under general heads. This is always the first step to any complete theory in natural philosophy.

This brief summary of the very important position held by the Milky Way for unravelling the mysteries of the stellar universe cannot fail to give us a new interest in that wonderful belt of light surrounding our stellar system. Even when looking at the comparatively pale features of its northern regions we can no longer fail to add to our mental picture the splendour of the southern parts, "trailing clouds of glory," with the glowing luminosity of stellar multitudes, the rifts and dark patches, and the offshoots in the Magellanic Clouds. Nor can we fail to associate even with its paler aspects the revelations of the telescope and the spectroscope. We recognize in this belt of light a key to the architecture of the heavens, probably a spiral nebula, one archipelago of stars out of a million, a mere fragmentary sample of the

immeasurable contents of infinite space. Our greatest Scottish astronomer, the late Sir David Gill, said to a friend : " My idea is that, if you could get up to the nebula in Andromeda, you would see our stellar system and the Milky Way looking very much as the nebula in Andromeda does to us."

When we realize the immense distance that separates us from the nearest edge of the Galaxy, and the inconceivable distance beyond, to which that belt extends ; when we realize that all the orbs contained therein are pursuing their courses in periods that are incalculable, we begin to look upon the Milky Way as symbolical of both infinity and eternity :

> " I saw Eternity the other night
> Like a great ring of pure and endless light,
> All calm, as it was bright ;
> And round beneath it, Time, in hours, days, years,
> Driven by the spheres,
> Like a vast shadow moved, in which the world
> And all her train were hurled."

And when we further realize that the distance we must penetrate to reach the external coils of our own island universe is as nothing compared to the distance of our nearest island-universe neighbour, we have to extend our notions both of infinity and eternity.

And there, on any one of those spiral nebulæ, people perhaps do see their own celestial sphere, just as we do ours, with their own private sun, their own private solar system, their own private firmament of stars, their own private Milky Way ; while our sun and solar system, and firmament of stars and Milky Way, which seem to us so important a part of the material universe, must be invisible to them except with a large telescope, aided by the boldest flights of photographic art. What a vast image of immensity is thus opened to our view! Unfathomable depths unfolding problems to delight countless generations of astronomers in the centuries to come.

Here we close the descriptive part of this book, and pass on to speculations on the " Origin of the Universe."

CHAPTER XVI

STARS, AND THEIR WIRELESS MESSAGES

PART I.—*Stellar Wave-Lengths and Signals*

I

"GOOD-EVENING, everybody!" In such words does the king of "broadcasters," in this age of wireless telegraphy, greet the "listeners-in" at the beginning of his conversations. He himself is in the transmitting or broadcasting station—2LO—in London, from which place an ingenious electrical apparatus is broadcasting ether-waves, all at the wave-length 365 metres, continuously, in all directions. These waves are not carried through air like sound, but, like light, through the ether which fills all space.

The broadcaster speaks into a microphone, and the microphone modulates the ether-waves so that the speech can be picked up on a telephone by any listener-in, provided his set be tuned to the ether wave-length 365 metres.

The telephone is nothing more than a very valuable accessory required, not for detecting the ether-waves, but only for reproducing the music and speaking. The marvellous part of the invention is that ether-waves of a chosen wave-length can be radiated from the station, and be picked up by a properly tuned set at a distance of hundreds or thousands of miles.

These ether-waves are the same as the light-waves that come from the sun; and Sirius, Capella, Betelgeuse, and all the stars that we see, are signalling to us in the same way. To some of us they almost seem, in their twinkling, to be saying "Good-evening, everybody!" All sentiment aside, however, this is a marvellous truth—that the stars are for ever broadcasting ether-waves of the same kind as 2LO does, only with a different wave-length.

The retina of our eye is so constructed that it acts as a receiver for these ether-waves and gets from them the sensation of light and colour. The stars, ever since they began to shine, have been broadcasting all kinds of signals by wireless telegraphy. Astronomers are now learning the codes for deciphering some of these signals. It was only sixty-six years ago that the principal key to their signalling

code was discovered. Now, every year we are becoming more familiar with their secret signal-codes. The spectroscope is to-day in constant use by astronomers for measuring the different wave-lengths that are being broadcast by each particular star. After that the signal-code is used for interpreting the message sent by that star.

Amongst the messages about itself that each star is for ever broadcasting we have already decoded many tales of extraordinary interest. By wireless telegraphy the stars actually tell us stories about the stuff they are made of, and this will be the main subject of the present chapter. Many astronomers believe that the stars have told us all about their life from infancy, and how they grew up to the full vigour of manhood, while many have passed to old age and even to second childhood. The stars tell stories, too, about their movements and their dances, their wanderings through the depths of space, their revolutions round invisible partners and their rotations about an axis like the earth's daily rotation ; also weird tales about whirling hurricanes that convulse their atmospheres ; and they are proclaiming their dimensions and the distance they are away from us. They tell us the temperatures that would be measured by a thermometer on their surface, and one of them tells stories even about its north magnetic pole, just like the magnetic pole on our earth that makes a mariner's compass point to the north.

Incredible as it may appear, all these true romances of astronomy, and more, are being continually notified by wireless to all inhabitants of the universe, and the spectroscope has enabled astronomers to register the messages, and often to interpret them.

II

To-day the newly acquired art of listening-in brings pleasure to millions of people, old and young. We enjoy seeing the keen schoolboy, wearing his head-phones, in front of his box of tricks. He turns a knob to pass his pointer over a circular scale of wave-lengths, and so he tunes his receiver to the wave-length of Edinburgh, Glasgow, London, or elsewhere.

Every boy knows that Glasgow's wave-length is 420 metres, London's 365, and that of Edinburgh is 328 metres. The stars use very much shorter wave-lengths. Here a metre would be of no

use as a unit. For measuring stellar wave-lengths we use a minute, invisible unit, called an ångstrom, after a celebrated Swedish experimenter. The ångstrom is so small that ten thousand million of them are needed to make up one metre.

It is truly a wonderful fact that our rough, clumsy human hands should be able to make instruments for broadcasting ether-waves whose length is measured in metres. But it is only the Creator who could make instruments for broadcasting the minute ether-waves that are measured in ångstroms. The human instruments are called *triodic valves* ; the Creator's instruments are called *atoms*. There are hydrogen atoms, iron atoms, and distinct atoms for all of the chemical elements. Each sends its own special wave-lengths, just as 2LO does. It is perfectly astounding to learn, as we do, that the wave-length radiated by a hydrogen atom is found to be the same whether the atom be in our laboratory, in the sun, in a star, or a nebula. So with other elements. These are " manufactured articles " of precisely the same construction in whatever part of the universe they may be found.

Our eyes are delicate receiving instruments that can pick up wave-lengths anywhere between four and eight thousand ångstroms. Each of the wave-lengths sent to us from any source of light is seen by the eye as a different colour : four thousand ångstroms look violet, six thousand look yellow, eight thousand look red.

So, when we regard a rainbow with its colours laid out in the definite order—red, orange, yellow, green, blue, indigo and violet —we recognize each wave-length broadcast by the sun as a different colour, all of them that we can see lying between four and eight thousand ångstroms. Obviously the eye cannot thus detect minute differences in wave-lengths, for only about seven colours in the spectrum can be surely distinguished from one another. For accurate measurement we use a spectroscope.

Everyone knows that the white light from the sun is a mixture of all those colours which are laid out in a row, according to their wave-lengths, in the rainbow. Instead of using a rainbow, however, we can look at the sun through a three-sided piece of glass called a " prism." We then see a band of colours in the same order. We call this coloured band a " spectrum," and a wave-length is known by its position on the spectrum.

Prisms can be mounted by an optician to make an instrument called a "spectroscope" in a form convenient for studying, and even for photographing, the spectrum. The astronomer can apply it to his telescope and then look through it at the sun or a star and see its spectrum, or, better still, he can photograph the spectrum. So he can measure the wave-lengths that are sent to us from each star, or detect any wave-lengths that are missing from the spectrum. Generally he sees a spectrum continuous from violet to red, with gaps appearing as dark lines. These represent missing colours at certain wave-lengths. There are wave-lengths that have been stopped by atoms in the atmosphere of the star. These wave-lengths are nearly always those that we have found, in the laboratory, to belong to the atoms of chemical substances that exist on our planet.

For example, on looking through a very good spectroscope at an electric spark playing between two bits of iron, we see that the spectrum of iron shines with thousands of bright lines, each of a different colour or wave-length. Next, on pointing the spectroscope to the sun, we find a continuous coloured spectrum with a dark line at each of these iron wave-lengths, thousands of coincidences. Thus we feel sure that iron atoms exist in the sun's atmosphere. So it is with nearly all of the materials found on our planet. They are generally found also in the sun.

Why, then, does iron in the sun show its presence by *dark* lines and not by the *bright* line which we see in the iron electric spark? Here is the answer, and it is the principal key for decoding the wireless signals of sun or stars:

The white-hot body of the sun or a star—whether it be solid, liquid, or gas so much compressed by atmospheric pressure as to be almost liquid—gives off a continuous spectrum from violet to red, for in that case the atoms are so close together that they jostle one another and are not free to vibrate in their own distinctive manner. But the iron or other atoms in a star's upper atmosphere are different, for they are not quite so hot, and they are free, and each of these cooler atoms absorbs the same colours that it would radiate under the electric spark. These colours or wave-lengths are therefore so weakened as to look like dark lines in the spectrum.

It comes to this: if we could examine the spectrum of the sun's

atmosphere without the bright-coloured background—that is to say, without the continuous spectrum of the sun's body—then we ought to see the lines bright instead of dark.

Now this is actually possible in a total eclipse of the sun. When the dark disc of the moon is passing over the bright disc of the sun there is a moment when, for a few seconds, the body of the sun is all eclipsed and yet there is a thin line on the border of the sun that gives light, and it comes from the upper parts of the sun's atmosphere that have no background of white light. This " flash " spectrum consists only of lines that are bright, where at other stages they looked dark on a continuous spectrum.

III

Now that we know all about broadcasting and all about the colour spectrum, let us try to imagine that we can see a man on the moon who is working with a wireless receiving-set, so perfect that he can tune it to detect every possible wave-length, even the most minute. Then we might watch him finding the wave-lengths that are being broadcast, as we watched the schoolboy.

First, he would be dealing with our earthly broadcasting. When his pointer is at 2600 metres he exclaims: " Hello ! Here is Eiffel Tower ! " At 365 metres: " Hello ! London ! " At 328 metres: " Hello ! Edinburgh ! " Then, on turning to much shorter wave-lengths, he could catch solar rays. At 5570 ångstroms he would shout: " Hello ! Here is hydrogen ! " Then, in succession, " Hello ! Sodium ! " and " Hello ! Iron ! " as he struck the wave-lengths of these atoms.

This is no joke. It is not used as a mere illustration. It is plain truth that the Creator's atoms are radiating just as are Marconi's valves, only at a different wave-length. Of course this man on the moon would not be using a telephone, because the sun does not use speech, and the telephone is not a necessary part of wireless telegraphy.

And now we understand how the spectroscope has, after much research, enabled us to say positively that the sun contains most of the chemical elements that are known to us on our planet. We cannot be on sure ground if we attempt to follow up this discovery

too far, for we do not know where the materials that constitute the sun, earth and planets originally came from. Certainly, if they were made out of materials originally existing in the form of meteorites, or comets, or nebulæ in the part of space now occupied by the solar system, this would explain why the earth and sun are made of the same materials, and we should expect to find that a majority of the nearest stars would be similarly constituted and would show a spectrum resembling that of the sun, where all the metals are conspicuous, and calcium particularly so. Later we shall see that this is probably true.

PART II.—*The Shape of our Stellar Universe*

Following upon the point thrown out in our previous section we may be desirous to form true conclusions from the signals sent to us by different classes of stars concerning the materials of which they are composed. To do this it is absolutely essential that we bear in mind much of what has been established by astronomers about the distribution of the stars in space and the form of the stellar universe, for it has been found that the stars are, for the most part, to be found in certain well-defined and limited regions of space. The stars in these regions are now spoken of by astronomers as forming the "stellar universe." And these do not seem to extend to anything like an infinite distance, although, of course, stellar distances are always so great as to be unrealizable by human minds.

The greatest fact about stellar distribution is that by far the greater number of stars are found among those constellations that are traversed by the Milky Way. This belt, often called the Galaxy, shows up in its full glory only on a brilliant moonless night. To the naked eye it looks like a broad wash of white paint on the celestial vault. It is an arch going right across the sky from horizon to horizon. It is continued through the constellations of the Southern Hemisphere which are below our horizon, and therefore unseen by us. In fact, it forms a flat ring that envelops the region of space occupied by the solar system.

We can trace it among constellations well known to us. On a summer evening we see it starting as a double band from Sagittarius

and Ophiuchus, and rising up through Aquila to Cygnus, where the two branches join together. Thence it passes as a single band through Cassiopeia, Auriga, Gemini and Orion. We then follow its course between Sirius and Procyon towards Puppis and Carina, and it continues its way among the southern constellations, going through the Southern Cross.

What looks to the naked eye like whitewash has its wonderful structure disclosed, even in a very small telescope, as consisting of myriads of stars too feeble to be distinguished by the naked eye. Larger telescopes reveal fainter, more distant stars. The most distant stars in the Galaxy that our telescopes have hitherto reached are ten thousand million times fainter than some of the first-magnitude stars. In the Milky Way we are thus limited only by the power of our telescopes. In all other directions, except on or near the Milky Way, an increase in power of telescopes does not go on adding prodigiously to the number of these faint stars, for the most distant stars in regions clear of the Milky Way are much closer to us than those in the region of the Milky Way. In fact it is now known that, inside the flat, extended ring of space containing the stars of the Galaxy, there is a nearly globular space (generally described as "bun-shaped") filled with nearly all the stars of our stellar universe that are not in the ring of the Galaxy (Fig. 19).

The Galactic ring contains probably a thousand million stars for every million in the bun-shaped space, because it extends to a distance so much greater. These recent discoveries about the form and structure of our stellar universe prove it to be based upon the Milky Way as a foundation, and the further we advance in new discoveries, the more clear becomes the fundamental importance of the Milky Way. The bun-shaped region has its own importance as being the region in which our own star, the sun with the solar system, is situated.

Following upon the discovery of the shape of our stellar system our interest is raised almost to the point of enthusiasm when we know that in many constellations there are minute luminous cloud-spots, called "spiral nebulæ," whose form is identical with that which belongs to our own stellar system. They have a bun-shaped central luminosity, surrounded by a ring of spiral luminosities. Each luminosity is due to myriads of minute stars, too close for us

to separate them. The resemblance to our own system is perfect, and they may be quite outside of, and disconnected from, our own stellar system. These spiral nebulæ might be regarded as "island universes" like our own stellar universe. Some astronomers go so far as to say that an observer on any planet that may exist in one of these "island universes" would see our Milky Way and bun-shaped nucleus as a spiral nebula.

The photographs of these spiral nebulæ, taken with very large telescopes, are perfectly beautiful and very suggestive. The finest

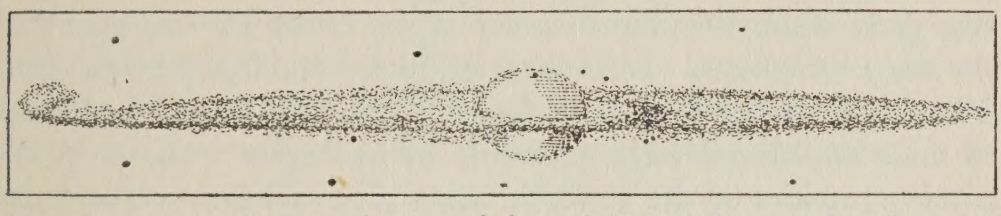

FIG. 19.—Supposed view, edge-on, of the Galaxy and the bun-shaped central part of our Stellar System. The Solar System is not far from the middle of the mass of stars; it resembles the Nebula on Plate XIII., p. 167

of them all is the "Whirlpool" nebula in the "Hunting-Dogs," a constellation south of the Great Bear's tail. This nebula probably resembles our stellar universe better than any other for reasons that will be told presently. Its special feature is a second glowing mass, like the central one, forming the outer extremity of one of the spiral arms of luminosity (see Plate XIII.).

PART III.—*The Spectra of the Stars*

I

Having prepared the ground in our two previous sections, we are able to understand the first discoveries that were made about the constitution of the stars.

Already the spectroscope had proved that the sun and earth, situated in the same region of space, are made of the same materials. It was natural to suppose that the sun is not unique among stars in this respect. It was natural to extend it to the other stars and to expect them all to show spectra, like the sun, with dark lines for all the materials found upon the earth. The very first application of a spectroscope to the brightest stars dispelled this expectation.

It was soon found that some of the brightest stars have spectra differing totally from that of the sun. This was a discovery of first importance. And yet, on consideration, this result might have been foreseen, for we have another means, more rare but more certain, for finding out the materials that may be in different parts of space. Meteorites are masses of matter that come like comets from interstellar regions and fall upon the surface of our earth. Some may come from the regions where Vega lies ; others from near Capella. Are these made always from the same materials ?

The answer is that they differ very much. There are, in fact, two great distinctive fundamental types, called the metallic and the stony meteorites. In the former, nickel and iron preponderate. The late Professor Graham, Master of the Mint, examined some of these and found large quantities of hydrogen confined in the pores or cavities of the meteoric mass. He told how astronomers had found many stars made of hydrogen. He went on to say : "This meteorite may be looked upon as holding imprisoned within it, and bearing to us, hydrogen of the stars."

As yet we have no evidence as to the regions of space from which these two distinct types of meteors emanate. It would, at present, be impossible to say that the ring of the Milky Way and the bun-shaped space are the two sources whence the two kinds of meteorites come. What the meteorites tell us certainly is that we ought not to expect to find that all stars are made of the same materials.

The new discoveries made by astronomers when they pointed a spectroscope at the stars last century were as numerous and surprising as those made in 1610, when a telescope was first pointed at the stars. The two great pioneers were Huggins in this country and Secchi in Rome. It is to the discoveries which began with Father Secchi at the observatory of the Vatican that attention will now be drawn, dealing with the materials found in the different stars.

II

Secchi invented a spectroscope which he could use with his existing telescope, so very simple in application that he was able to make a rapid general survey of all the brighter stars. The results he arrived at were unexpected and surprising. Finding that they did not seem to be of uniform constitution, he set to work

to find whether the spectra could be classified in a limited number of types. At the end of his laborious survey he was able to assert that there is "a fundamental distinction between the spectra of stars, according to *a small number of types.*" This is the wonderful generalization which to-day lies at the base of all our knowledge about the constitution of the stars.

He found that nearly all stars belong to one or other of two distinct types, I. and II. The remaining spectra stars he examined were red in colour, and had spectra of two other quite distinct types, III. and IV.

He also discovered from his first great general survey that *some of the different types are localized in particular parts of the heavens.* Far too little attention has been given by theorists to this second discovery, the truth of which is now completely established. In the *British Association Report* for 1868 we can read about all the fundamental facts that Secchi had discovered at that date.

Nothing could ever obliterate from my mind the memory of Secchi when I was in Rome in 1871. I was a youngster, fresh from Cambridge. Secchi was, to my mind, one of the greatest of men, from his discoveries. I had a letter of introduction to him, I think from Airy. He invited me to spend a night with him, at the Vatican Observatory, with his spectroscope. I expected to have difficulty in seeing the spectrum of so feeble a light as a star.

Secchi began by pointing his telescope on Sirius. During a period of about five minutes he was carefully adjusting the apparatus to give the very best effect. At last he stood back and invited me to look. I shall never forget the wonder I felt at the splendid brilliance of that spectrum, with its four dark lines across the spectrum, all due to hydrogen. I knew the solar spectrum well enough to see at the first glance that the spectrum of Sirius was totally different. It seemed to establish the fact that Sirius must consist almost entirely of hydrogen gas ; whereas the sun shows lines due to most of the substances found on our earth.

He next showed me the spectrum of Capella, a star of his Type II. This was totally different. Of course I could not identify the numerous dark lines crossing the spectrum, but I was quite ready to accept what Secchi told me, that "this spectrum is exactly like

that of our sun." In both Capella and the sun the hydrogen lines are far less notable then in Type I., the characteristic lines being calcium and various other metals.

Then he pointed his spectroscope and telescope to Betelgeuse, the red star in Orion's shoulder, whose spectrum is of the Type III. While its spectrum had some resemblance to that of Capella, its characteristic feature was the addition of a number of dark bands or flutings of unknown origin. We now know that these are due to absorption of light by *titanium oxide* in the atmosphere of the star.

I cannot now recall whether Secchi then showed me a spectrum of Type IV., found only in certain faint, blood-red telescopic stars. This resembles Type III., except that the added bands or flutings have a totally different character. They were correctly ascribed by Secchi to absorption of light by *carbon compounds* in the atmospheres of these stars.

Secchi also found that the spectrum of Rigel, and most of the Orion stars, though resembling that of Sirius, and obviously belonging to Type I., had in addition a number of very fine lines. We now know that these lines belong to helium, an element that was discovered by Ramsay as a terrestrial element in 1895.

III

Now, we are able to set out Secchi's four types of stellar spectra, and the chemical constitution indicated by each :

TYPE I., like Sirius, essentially a hydrogen spectrum ; with a subsection, like Rigel, showing also helium.

TYPE II., like Capella, solar stars, marked by calcium, metals, and most of our terrestrial elements.

TYPE III., like Betelgeuse, red stars, like the solar type, with titanium-oxide added.

TYPE IV., telescopic, crimson stars, like the solar type, with carbon compounds added.

Nearly all the stars he observed belong to Type I. or II. Some few stars have a spectrum intermediate between Types I. and II.,

or between Types II. and III.; but no stars have spectra intermediate between Types I. and III.

The discoveries of the early pioneers, such as Huggins and Secchi, have been enormously extended by later researches. But Secchi's great general classification remains fundamental. Really, he named five types, due to (1) hydrogen; (2) helium and hydrogen; (3) calcium and metals; (4) titanium; (5) carbon.

A very great additional interest, for people who do not own spectroscopes, arises from the fact that all of these five types can be generally foretold by anyone. For it is found that stars which differ in spectroscopic type can generally be seen to shine with different colours.

Sirius, Vega and all stars of Type I. are white. Some of them may seem to have a bluish tinge, and Secchi noticed that all the Orion stars, like Rigel, have a greenish tinge. Still, they are all white stars. Capella, and all stars of Type II., the solar type, are, on the other hand, distinctly yellow. Betelgeuse, Antares and other stars of Type III. are red; those of Type IV. are crimson or blood-red. People vary in their readiness to detect these differences.

PART IV.—*Hypotheses*

I

Many hypotheses have been propounded to account for the different types of spectra. All of these are regarded by the true astronomer as being merely tentative. When so regarded, they are useful for indicating directions of research that will tend to support or refute one or other of these hypotheses. So in time we may hope to reach truth. The particular hypothesis most generally preferred by astronomers fluctuates from decade to decade. Here it will be well to concentrate upon a single one of these hypotheses that may be only partially true, but which seems to the present writer to be at least the most obvious one, and not based upon any improbable assumption. It is the only one that is not in conflict with one of the main facts of observation, the localization of spectral types in space.

The obvious interpretation of the different types of spectrum is

that about one half of the stars, like Sirius, are composed chiefly of hydrogen ; that some of these, like Rigel, are unique in containing much helium in addition ; that nearly all of the remaining half of the stars, like Capella and our sun, are composed of the same materials as the earth is made of ; that the red stars, like Betelgeuse, are composed largely of titanium oxide ; and the crimson stars of Type IV. are composed largely of carbon compounds.

If we accept these obvious conclusions about the materials that stars are made of, Secchi's hint that stars with the different contents are to be found in different constellations opens out a totally new aspect of the universe. The suggestion is that stars have been made out of the materials prevalent in each region of space by a condensation of these materials under gravitation. And our task is reduced to finding what regions of space contain the various materials found in the spectra of different stars.

We already know that our stellar universe seems to be a limited region resembling, in shape, one of the spiral nebulæ, for it consists essentially of two parts : (1) the wide flat ring filled with the clouds of stars that constitute the Milky Way ; and (2) the great bun-shaped space inside the ring with the solar system not very far from its centre.

The researches carried out since the time of Secchi prove that the first of these parts is the home of the hydrogen stars ; and the second is the home of the stars of the solar type. This stands as a general truth, in spite of the fact that in the course of ages many stars may, by their proper-motions, have passed from the region of their birth to the other region, and make exception to the general rule. Moreover, it is quite obvious that at the boundary between the two regions, stars would have built themselves up out of the constituents of both regions, and it is a remarkable fact, giving strong support to this hypothesis, that we find composite stars whose spectra contain every proportion of the two types. We have a continuous series of star-spectra passing by slow gradation from the Sirius type to the Capella type of spectrum. Yet again, Kapteyn found that the general average distance from us of the hydrogen stars is two and a half times that of the solar type, just as we should expect if the former were in the Milky Way and the latter in the bun-shaped space.

II

This localization of stellar spectra in space is by far the most wonderful and the most illuminating positive fact, in relation to the structure of the universe, that has as yet been revealed to us by spectroscopic research.

Some of the other spectral types are still more precisely localized, most especially those of a fifth type which Pickering added to the

FIG. 20.—Showing a representation of our Stellar Universe shaped like the Whirlpool Nebula (shown in Plate XIII.). The spirals are the Milky Way. The terminal cloud on one arm contains Helium stars. The central Globe is the bun-shaped region in which our Solar System lies

four types of Secchi. A few words should be said about the intense localization of the helium stars. These are nearly all found in the constellations Orion and Carina, and the short arc of forty degrees that connects them, along the border of the Milky Way. The distance from us of the stars on this short bit of the Milky Way is suspected to be even greater than the hydrogen stars in the Milky

Way itself. They seem to lie in a limited region, or cloud, of concentrated helium, at the outer boundary of the Milky Way. This reminds us of the concentrated secondary nucleus of light in the Whirlpool nebula at the outer end of one of its spiral arms (see Fig. 20. Compare it with Fig. 19, p. 189, and compare both with Plate XIII.).

Here again, as with Types I. and II., we find every stage of intermediate spectrum, between the helium and hydrogen types. But there is no part of space where the helium and bun-shaped spaces can commingle. So there are no intermediate spectra between helium and Type II.

Types III. and IV., on the other hand, would be, on this hypothesis, in spaces adjacent to, or enclosed by, the bun-shaped region, for intermediate spectra between each of them and Capella are found in a continuous series, and none between their spectra and those of the hydrogen, Milky Way type.

The localizations of Types III. and IV. have been shown clearly by Pickering, Plummer, Espin and others. All their results seem to be explained if there be two non-intersecting rings of space within the bun-shaped region, one containing titanium oxide, the other carbon compounds, one in the plane of the Milky Way, the other slightly inclined to it.

III

It is very satisfying to find that we have found a scheme of construction of the stellar universe that fits the main facts revealed by the spectroscope, and is in agreement with what we already knew about the shape of our universe. It is particularly pleasing to see how the variegated spectra all fit into one continuous succession from helium to calcium, and thence into two branches, titanium and carbon.

But there are many facts that are not so easily explained. One is that the temperatures of stars are found to vary with spectral type. Broadly, we have to account, on this hypothesis, for the outer regions of the Milky Way being hottest, and the central regions of the universe much cooler. There is also some difficulty in understanding why the size of stars should vary with spectral

type, or with the regions we have assigned to them, as seems to be the case. Such difficulties must inevitably arise from our still imperfect knowledge of natural philosophy. For we are now only in the twentieth century.

The theory which has now been examined must not be taken as being necessarily true. It is certainly the obvious reading of the facts, but is repudiated by the vast majority of astronomers of to-day, who at present have a fancy for looking upon all stars as being made of the same materials as our earth. They ascribe the different spectra to different temperatures ; and they consider that every star, during its life of visibility, shows in succession the whole series of spectra from low temperature to a maximum, and back again to coldness. It is a very ingenious and attractive hypothesis, as will be seen from the concluding chapter of this book.

All such hypotheses must, in the present state of knowledge, be speculative. The locality-hypothesis and the age-hypothesis are both intensely interesting ; but we are still very far from knowing why the stars are shining in the way they do. The fact remains that the stars are making great efforts, by wireless telegraphy, to give us the information we are trying to lay hold of, and every year adds to the knowledge that will some day tell us the whole truth.

CHAPTER XVII

FAIRY TALES, BY ASTRONOMERS

I

It would be a pity, and the reader would probably miss an intellectual treat—certainly much quiet amusement—if this book should end without reference to some of the extraordinary speculations current to-day among mathematical physicists about the stars. Their deductive process of reasoning, from data that too often are not the result of observation, is of course unreliable ; but some of these excursions into the unknown possess so great a charm that we are often perhaps too ready to accept them as proved, the wish being father to the thought.

Until nearly the end of the nineteenth century our great astronomers and natural philosophers were very cautious in distinguishing between what is possibly, probably, or certainly true. They disliked mere guessing, and did not believe in fairy tales. They always accepted Sir Isaac Newton's Rule I. for philosophizing : "Never invent a new cause or theory for explaining any fact, if the known causes or the established theories suffice."

In the twentieth century a new world has appeared. Fairy tales, fables and fantastic dream-stories found favour first among the physiologists. Now the whole world of science is peopled by fairies and genii, by necromancers and mystics.

Even astronomers of the highest repute do now delight in mathematically presented paradoxes, and they claim that their hypotheses are at least the most probable deduction from the present imperfect data. These flights of fancy give a superlative pleasure to those intellectual people who are furnished with a wide imagination, even though they know them to be at present only a fairy tale or the story of a dream.

What is here meant by these terms is made more clear by an example. Long before the Christian era, the only explanation of the retrograde motion of planets was that of Pythagoras, not unlike our modern theory of the solar system.

Later, a wonderful fairy tale arose from the introduction of epicycles by Apollonius and excentrics by Hipparchus, according

to which the planets were supposed to move along orbits of marvellous shape This fanciful dream lasted for nearly two thousand years.

Since that time no other fairy tale has taken greater hold of distinguished mathematicians such as we have with us to-day—who are quite as great pundits in their way as were Apollonius, Hipparchus, Aristotle and Ptolemy—than the great wonder-story called *the evolution of the stars*; to replace what they all admit to be the more obvious (*Pythagorean*, let us say) interpretation of stellar spectra.

In Chapter XVI. we learned that, among the limited number of types into which stars can be divided by their spectra, each type exhibits the predominance of a different kind of chemical substances. And, broadly speaking, we may say that each type favours some particular region of space in the stellar universe. And the *obvious* interpretation of the facts was given in that chapter. To-day, however, and for the past ten or twelve years, people of imaginative tendencies, whose mathematical dexterity is quite equal to that of Apollonius, have been developing a theory that all stars are made of the same stuff, in spite of the spectroscopic evidence—a theory which, as developed by them, cannot possibly be reconciled with the known localization of stars of certain types of spectrum.

To-day, the reason generally given by some astronomers why the spectroscope does not tell us what a star is made of is this: they say that the spectrum's dark lines from a star only tell us the material existing in an upper layer of the star's atmosphere. Its atoms in that layer absorb certain colours from the white light that reaches us from the dense central parts of the star. The assumption is that the particular materials whose presence in that layer are made known to us by the spectrum depends altogether upon the star's temperature.

Why this should be so, no one has ever understood. And it would puzzle the best of chemists to say what special property is possessed by *titanium oxide* that causes it, at a temperature of three or four thousand degrees, to be the one special substance that is present in the upper atmospheric layer, and so dominates the spectrum of stars of that temperature. That it does so dominate the spectrum of that type of star is an absolute proved fact.

If any reason could be found for this extraordinary temperature-effect on certain materials, we could safely advance one more step. For, as a matter of fact, we have, by more than one method of inquiry, found it to be almost certainly true that all the types of star, as defined by their spectra, are at a different temperature for each type.

If only we could understand the supposed temperature-effect upon titanium oxide, calcium, hydrogen, helium, etc., we might now be able to admit that the spectroscope does perhaps fail to tell us even the principal constituent materials in a star, and only indicates a star's temperature near the surface of its atmosphere. Even then the fabricators of our beautiful fairy tale would not be satisfied. From their point of view it is too simple a thing to be satisfied with the statement that *all stars are similarly constituted, but at different temperatures, with a continuous succession of temperatures, from fifteen thousand degrees for helium stars down to three thousand degrees for titanium-oxide stars.*

So these ingenious people invent a gratuitous but perfectly beautiful addition to the assumptions that make up our fairy tale. They invite us to behold a universe of stars in which not only are all stars alike, except in temperature, but further, that every star passes, during its existence as a luminous star, through the whole complete range of temperatures which belong to all the types of spectrum from helium to titanium oxide. This grandiloquent assumption leads us from the field of observation and fact into the fairy world of beautiful aspirations, where conviction comes more from the cheers, and the waving of flags, and the slogan of "Evolution," than from cautious and reasoned judgment of both the *pros* and the *cons*.

II

The Evolution of the Stars.—The late Professor E. C. Pickering and his assistants at Harvard College Observatory, U.S.A., have followed up Secchi's preliminary classification of star-spectra, and have confirmed, along with others, his discovery of the localization of most, if not all, of the different spectrum types. They have denoted his types by letters of the alphabet, and intermediate types

by other letters. The classes so named run into one another in a regular sequence, ending with threefold branches, thus :

$$\text{P,O,B,A,F} \begin{Bmatrix} \text{G,R,N} \\ \text{G,K,M} \\ \text{G,} \quad \text{S} \end{Bmatrix} \text{ wherein}$$

P-spectra show the bright lines of nebulæ.
O-spectra, the bright lines of Wolf-Rayet stars.
B-spectra, the helium spectrum of Orion stars.
A-spectra, broad hydrogen lines in stars like Sirius.
F-spectra, intermediate.
G-spectra, solar type, lines of calcium and most of the metals.
K-spectra, intermediate.
M-spectra, the spectrum of titanium oxide.

The detailed descriptions are in the *Harvard Annals*. The two other branches from G, to N (carbon compounds) and to S (zirconium oxide), are seldom alluded to in the evolution theory, which is not so simple when account is taken of these branches. For the sake of simplicity in explaining the evolution theory these branches, along with the P and O types, are best ignored, during its exposition.

Temperature.—Several independent methods have been used for estimating the surface-temperature of stars in degrees centigrade. Professor Sampson, of Edinburgh Observatory, the Astronomer Royal for Scotland, found these values :

Star	*Spectral Type*	*Temperature Deg. C.*
γ Cassiopeiæ	B0*p*	16,900
α Andromedæ	A0*p*	15,500
α Pegasi	A0	15,000
α Cygni	A2*p*	12,500
α Lyræ (Vega)	A0	11,200
α Aquilæ (Altair)	A5	10,000
α Cephei	A5	9,200
β Cassiopeiæ	F5	8,800
α Persei	F5	7,500
α Ursæ Minoris (Polaris)	F8	6,800
γ Cygni	F8*p*	6,600

Star	*Spectral Type*	*Temperature Deg. C.*
α Aurigæ (Capella)	G0	5,500
ε Cygni	K0	4,700
α Cassiopeiæ	K0	5,100
ε Pegasi	K0	4,200
β Pegasi	M3	3,600
β Andromedæ	M0	3,500

N.B.—Gradations from one class to the next are indicated by numerals 0 to 9. The addition of the letter *p* indicates some peculiarity in the star's spectrum.

Other observers differ a little in the actual temperatures. All however agree in the steady fall of temperature, from B to M, of the spectral types.

Energy of Solar and Stellar Radiation.—The sun, like all stars, is constantly radiating light and heat through space. When trapped on our earth these create winds and evaporation, and chemical action on vegetation. This energy of radiation from the sun is a power of doing work. It turns all our windmills and water-wheels and turbines, and it makes the coal that works our steam-engines. Coal has been spoken of as "bottled sunlight." It is quite clear that the sun's radiation means a large expenditure of energy. If the sun, or a star, were not constantly supplied with fresh energy in the shape of heat it would become cold.

People have always been puzzled to know how this immense quantity of energy of radiation in the sun, or a star, can be maintained. Helmholtz assured us that this heat is supplied by a slow contraction in size of the sun's diameter. If you suddenly compress air or any gas in a cylinder, by pressing a piston into the cylinder, you heat the air or gas so much that a piece of tinder can be lighted. The contraction under its own gravity of the sun's volume is a true cause for adding to the sun's heat, as Helmholtz and, later, Homer Lane said. But the amount of heat has been proved to be quite insufficient for supplying what the sun loses by radiation. The same conclusion applies to the stars. There must be some other source of heat, and this is still a puzzle to astronomers.

Before the fallacy had been exposed, in the case of the sun,

Lockyer accepted it as applying to the stars, when he laid the foundations of the modern evolution theory. And this erroneous explanation of stellar heat has unfortunately been used, even until now, as the basis of the theory of stellar evolution. Still, a dream-story, even when it defies the laws of nature, can be very interesting. Let us see how the fairy tale works out.

III

The foundation of the theory of evolution is as follows.

Once upon a time the sun, or any star, was an immense cold ball of nebulous matter or meteoric dust. Its diameter was to be measured in thousands of millions of miles. Its own attraction of gravitation compressed it, making it hot and, later, luminous. The star continued to become hotter and to shine brighter, in spite of its diminishing size, because of its increasing temperature. So, a star, like Rigel in Orion, began by being a red M-star, at the lowest temperature that made it visible. It got hotter and hotter, passing through the spectral types K, G, F, A, until it reached its present state of a very white-hot B-type star.

A time comes, however, to each star when it is so much compressed that any further compression is very slow, and the heat developed is not enough to maintain the temperature of the star. So, after reaching a very high temperature, which is higher for the more massive stars, they each begin to cool more and more, until they once more become cold and invisible. All this time the diameter of the star has been contracting.

Capella is a star at the same temperature as the sun. It will probably (according to the hypothesis) begin to cool without rising in temperature very much more. The sun is supposed already to have passed the turning-point and to be getting colder as well as smaller.

In this way, if only Helmholtz's theory of solar heat could be correct, a very massive star like Rigel might be expected to go twice through all temperatures, and pass twice through all the spectral types, thus :

Temp.	3000°		6000°		10,000°		15,000°		10,000°		6000°		3000°
Type	M	K	G	F	A		B		A	F	G	K	M

A less massive star, like the sun, might reach no higher temperature than 10,000° (A) or 6000° (G), and then retreat down to 3000°, and ultimately to the coldness that means invisibility.

The Absolute Brightness of Stars.—Hence the most remarkable consequence of Lockyer's hypothesis is that at any temperature, say 3000° to 4000° (M or K stars), there must be two classes of stars at the same temperature: giants of great brightness owing to their huge surface, and dwarfs of feeble luminosity owing to their contracted size. Now their brightness, as seen by us, depends on their distance from us. So we cannot compare their absolute brightness (with which we should see them shining if they were all at one distance) until we know their distances; and the distances of all stars are so enormous that astronomers have not the means for truly measuring any except the nearest ones.

Unfortunately for these measurements, as a test of the giant and dwarf theory, those who have undertaken the measurement of stellar distances had to select for examination those stars which might be expected to be near to us. The stars that look brightest are probably among the nearest to us, and the stars whose proper-motion among the stars is greatest are probably also among the nearest ones.

So it happens that the distances which we know are those of stars so chosen for measurement, and consist of (1) very large bright stars, and (2) stars of high velocity; and we know that these last are often the smallest stars in the sky. Thus when we examine the real or absolute brightness of stars whose distances are known, the stars are naturally found to be in two groups, either very large or very small—giants or dwarfs. After Hertzsprung had drawn attention to the existence of these two groups, giants and dwarfs, Russell, not quite correctly, took it as a proof of the correctness of Lockyer's theory, although there had been little chance of including any stars which there may be, intermediate between giants and dwarfs. This result of the special choice of stars was not noticed at first. Russell also accepted the erroneous theory of Helmholtz and Homer Lane to account for the maintenance of stellar heat.

IV

More Fairy Tales.—And so began the great entrancing fairy tale about giants and dwarfs. Russell's clear and potent voice was broadcast. The echoes of it resounded everywhere. It has been only in the last year or two that a fair number of cool-headed astronomers, including men like Hertzsprung and van Rhijn, could get a hearing. These showed us how it happened that most of the stars whose absolute brightness is known must have been chosen from among the largest and smallest stars ; and there is really no proof at all that intermediate stars do not exist. The giant and dwarf story may be true—and must be true if Lockyer's and Russell's theory is correct—but it is certainly not proven. And if it be true this would not prove Russell's theory to be true. The most fatal objection to Russell's or Lockyer's, or any theory of evolution, is the known localization in space of spectral types of stars.

" It is really too much to ask anyone to believe, except in the way he believes a fairy tale, that every massive star is born in the M-region mapped out by Plummer, then goes into the G-space inside of the ring-shaped Galaxy, then enters the Milky Way as an A-star, and then reaches the confined region in Orion and Carina where B-stars live ; and that it then retraces its steps while retracing the spectral types, B, A, F, G, K, M.

Another chapter of romance now begins. One of our most brilliant story-tellers, a veritable " Tusitala " of astronomy, was led by his mathematical formulæ to tell us that the real brightness of stars does not depend to any extent upon temperature, density, or anything but mass. He told us that, if there are both giants and dwarfs among the stars of any one class, there would be one law for the giants, and another for the dwarfs. But he found no difference. So, for the moment, he rejected the stories about giants and dwarfs, the fortress and the citadel of our dream of stellar evolution, the pearl among astronomical fables, the " Alice in Wonderland " of astronomers, for nearly ten years.

But our weavers of fairy tales are not like those people who could give up the " Hatter " or the " Humpty-Dumpty " of Lewis Carroll's creation without some attempt to put them on their feet again.

So it was that our "Arabian Nights'" entertainers had new dreams and revelations that defied the laws of nature, and went some way towards rebuilding the tottering edifice. But it was dangerous work, this rebuilding; and sober-minded listeners were amazed at the contempt shown for Newton's Rule I., and for Bacon's method of inductive reasoning, which had been so well exemplified by Tycho Brahe and Kepler, and has ever since been the bulwark of true science.

We may well ask now what reasons did all these astronomers give for departing originally from what they all confessed to be the obvious interpretation of the spectra.

I find that Lockyer's reason was only that he considered it more natural to assume all stars to be made of the same materials, and that the theory of the sun's heat given by Helmholtz was then supported by Kelvin and Tait.

George Hale tells us that he took the same view for another reason. It seemed to him that an evolution theory of the stars was a fitting complement, and some confirmation, of Darwin's evolution theory of animals.

Russell again tells us that to himself the most convincing fact to make him adopt the evolution theory of stars was the linear continuity of spectra from B to M. This was before the other branches, from G to N and S, had been discovered.

Our romancers are still at work propping up the structure. Let us hope they may succeed. It would be a pity if the beautiful dream were to fade away like the Greek mythology.

But they have an arduous task: (1) They must reconcile the theory with localization of spectral types in space. (2) They must find a new source of heat in the stars. (3) They must prove that there are no stars intermediate between giants and dwarfs. (4) They must explain the relation of certain chemical elements in stellar spectra (especially oxide of titanium) to temperature. (5) They must account for the absence of continuity of spectral series as shown by the M, N and S branches.

But these obvious difficulties are small in comparison with those evoked by the mathematical exponents of the fairy tale in their attempts to improve it. The next fable may turn out to be a mixture of the *space*-theory and the *time*-theory. Meanwhile it is interesting

to look at some of the wrigglings of the extremists. Before doing so it is well to give the answer to a very natural question by some reader : "We have always been told that mathematical reasoning is infallible. How comes it then that these brilliant mathematical researches lead to paradoxical results, and have to be supplanted ?"

The simple answer is that when true facts are put into mathematical language, and reasoned upon by the rules of mathematical processes, the result is absolutely true. In our case the facts are not always indisputable, but the important point is this : owing to the still imperfect powers of our mathematical analysis our equations are sometimes insoluble, but would cease to be so, and would make everything clear, if only we were allowed to assume that some other simple equation is true. The temptation to make this little prevarication, and to give a plausible excuse for the transgression, is to some minds irresistible. Some of them yield to it, and their authority, well earned from past solid, conscientious work, draws into their train a following of believers, who proclaim the results everywhere as scientific truths.

V

There are at present two very distinguished Fellows of the Royal Astronomical Society, brilliant mathematicians, who are the most marvellous weavers of tales about fairies and genii, and giants and dwarfs. They delight the Fellows at each meeting by tales of the wildest imaginative power. At one meeting the first tells tales about beneficent fairies. At the next, the other proves that these new people must be malignant genii ; and so it goes on. Meantime the audience enjoys just the same kind of exhilaration, and precisely the same degree of conviction, as they used to do from the products of Grimms' or Hans Andersen's imagination.

The evolution theory is already based on a number of assumptions, but those that are now being invented to support its foundations are staggering in their import. It will be amusing to take note of a few of these.

In 1924 Professor Eddington, as has been told on page 205, found, by calculation compared with observation, that the whole fabric of

evolution of stars, which he had accepted, must be wiped out, and that giant and dwarf states of a star's life were impossible. He felt himself to be like the Arabian magician who, having imprisoned one of the genii in a bottle, let him out in the hope that his great power would be used benevolently. He found that he had released a demon who began a course of destruction. Eddington himself put it mildly when he said : "Some new results have confronted us which seem to call for a considerable modification of the theory of stellar evolution."

Thereupon he began by converting the atoms of some stars into a new kind of atom, and this got over a part of his difficulty ; but it was playing with fire, and, to safeguard the evolution theory, he had to assume that a star is always losing part of its mass.

At this stage all the authors of fairy tales joined in a new one to explain the continuous losing of mass by stars. They invented the marvellous dream-hallucination that the maintenance of a star's energy which is dissipated in the radiation of light and heat is due to the annihilation of its substance. The great new creed has been thus announced : "The origin of a star's heat is its mass." If you, kind reader, know, precisely and physically, what this means, you know more than do the authors of the creed. It was easy to give an appearance of reality to this astounding assertion by stating the exact figures, and now we are told positively that the mass of the sun is diminishing at the rate of four and a quarter million tons every second of time.

One of our two great magicians tells us ingenuously that this conversion of a star's mass into light and heat *must* be true *because* he sees no other loophole of escape that will save the evolution theory. "To avoid a complete upheaval of this [the ideas of evolution hitherto expounded], we *must* admit substantial decrease of mass, and therefore *the annihilation of matter*." This is only one example, out of many, where dream-stories contradict every established fact about the properties of matter.

Our most delightful and accomplished entertainers at the Astronomical Society enthral their hearers with many wonders, and of course these are by no means always, or even generally, based on doubtful premises. They tell us that, while the surface-temperature of the sun is six thousand degrees, it rises at the centre to forty

million degrees. The greatest assumption contained in that statement is that gases at that inconceivable temperature follow the same rules as at terrestrial heats.

Another wonder defying all experience is their assertion that a small star, the companion of Sirius, must be three thousand times heavier than gold or platinum, our heavy metals. So that a coin of the size of a penny, if made out of the substance of which this star is made, would weigh nearly two hundred pounds. You would not be able to lift it off from the table.

Eddington has lately given us a perfectly enchanting collection of fairy tales (*Lectures*, King's College, London, 1926), and, with charming frankness, concludes by saying: "It will be seen that we have already encountered a number of difficulties. I daresay we can wriggle out of these somehow, but that kind of proceeding is not very convincing." Then he adds that the explanations he has attempted in support of any evolution theory always "fizzle out, ending with a glimpse of the obscurity which marks the frontiers of present knowledge."

Our second "Arabian Nights'" entertainer has an unsurpassed command of the English language, and at many a meeting of the R.A.S. he expounds the results of his mathematical researches into the constitution of the stellar universe so clearly as to force conviction into the hearts of his hearers.

There was once a "Nebular hypothesis" of the solar system, first hinted at apologetically as a phantasy by that serious and rigidly sound astronomer Laplace, not in his great treatise but in a popular book on astronomy. It was taken up solemnly by men of the Herbert Spencer type, and made much of in popular lectures. No serious astronomer of the old guard paid any attention to it.

Now Dr Jeans and others have gone much farther. Dr Jeans does not copy Hans Andersen in his fairy tales. He does not begin by saying: "Once upon a time." He is much more definite. He begins his greatest fairy tale somewhat in this way: "*At the time when time began to be*, there were thousands of enormous rotating balls of nebulous matter careering through space, influenced by gravitative attraction."

Starting from this point, he goes on to show that spiral nebulæ would inevitably be formed by tidal actions between neighbouring

masses. Then the spiral arms would break up into condensations, to make suns or stars. And in the very rare case where two of these suns passed *very* close to each other, tongues of nebulous stuff would rise up in gigantic tides at opposite sides of the sun, would be torn off and broken up, and would inevitably form planets like our earth, with land and seas, and (not so inevitably) with vegetable and animal life.

In this superb fairy tale each primordial nebulous mass forms eventually, and without any likelihood of failure, a spiral nebula, which is a complete stellar universe like our own stellar universe. His calculations lead him to forms and shapes through which such masses must pass during æons of ages, and these forms are exactly reproduced in the photographed marvels of the spiral nebulæ.

He makes it obvious to the uninitiated that the Great Nebula of Andromeda contains enough material to make two thousand five hundred million stars like our sun—just about the same number of stars as he tells us are to be found in our own stellar universe.

Again, he finds that his stars get misshapen by rotation, and, generally, each one must split into two, revolving round each other, close together, as spectroscopic binaries. Thereafter they must lose mass by their radiation, and do not attract each other so strongly. Consequently they drift farther apart, so much so that they can later be seen as visual binaries.

In fact you find in this cosmogony that if you start with his huge revolving masses of vapour or gas, and even dust-particles while cold, you are bound to end up, if you accept a few minor assumptions which he makes, with spiral nebulæ, or stellar universes exactly resembling our own stellar universe in every particular. But you must bear in mind the fact that this is the truth only if his assumption should prove to be correct.

This is perhaps the most complete and delightful of all the fairy tales with which astronomers have delighted us. Even those among us who do not consider it right to speak of these tales as being the truths of science enjoy them, and they are doubtless helpful to every astronomer, as being suggestive of directions in which truth may lie.

The charm of these fairy tales is equalled only by the charm of the tellers. Like a conjurer at the Egyptian Hall of Mystery, they

produce rabbits out of hats and, with tongue in cheek, as the whole audience knows perfectly well, they pretend it is the real thing. So it is that in these present days every Fellow of the Royal Astronomical Society feels himself fortunate and privileged when listening, month after month, to our incomparable romancer, every time that, with the most placid expression, he asks their acceptance of well-reasoned theories, or, it may be, of the most appalling paradoxes or antinomies.

Eddington, as already quoted, concluded his King's College lectures by a frank admission of this humour. Jeans ended an exposition of his cosmogony in the same strain as follows :—" And so it comes about that the cosmogonist can never be justified in stating the result of his investigations with any confidence ; if he must make a positive assertion, the only one he is entitled to make is that in cosmogony we know nothing at all for certain."

Could any words be more frank and altogether admirable ?

APPENDIX I

TEN USEFUL ASTRONOMICAL MEMORANDA

I CONSTANTLY find it useful to remember the following closely approximate data. This is not difficult when the simple hints now given to assist the memory are adopted :—

I. Degrees, minutes and seconds expressed, as the ratio of arc to radius, in decimals. To get the first figure :

For 1°, after decimal point, add **1** nought, and a **1**.
For 1′, after decimal point, add **3** noughts, and a **3**.
For 1″, after decimal point, add **5** noughts, and a **5**.

Only remember, for 1°, you must add 75. Thus we have :

1°=·0175 . .	more accurately,	0·017453.
1′=·0003 . .	,, ,,	0·0002909.
1″=·000005 .	,, ,,	0·000004848.

II. Number of hours in a year of 365 days = 8,760 } Both begin with **8**.
Number of seconds in a day of 24 hours=86,400 }

N.B.—8,760 steps down from 8, **1** unit each step, and has **1** nought.
86,400 steps down from 8, **2** units each step, and has **2** noughts.

III. Number of seconds in a year is about $31\frac{3}{4}$ (say 32) millions.
Velocity of light=300,000 kilometres=186,000 miles, per second.
The product of these two is **1** light-year (lt.-yr.).
1 lt.-yr.=9,463,000,000,000 kilometres=5,880,000,000,000 miles.
1 lt.-yr.=63,290 astronomical units. (Distance of sun=1 unit.)
1 lt.-yr.=3·26 divided by a star's parallax, in seconds.

IV. $\left\{\begin{matrix}\text{Cross-motion}\\ \text{in kilos. per sec.}\end{matrix}\right\} = \left\{\begin{matrix}\text{Annual P.-M.*}\\ \text{in seconds}\end{matrix}\right\} \times \left\{\begin{matrix}\text{Distance in}\\ \text{light-years}\end{matrix}\right\} \times 1{\cdot}445$

V. 1 metre=**3** ft. **3** in. and **3** eighths; or, closer, 3·280843 ft.
1 inch =25·4 millimetres, very exactly.
1 mile =1·6 kilometre; or 5 miles=8 kilometres.

VI. π=the ratio of a circle's circumference to radius.
π=3·1415926535895. This long number can easily be remembered by counting the letters in the following (Archimedes being spelt with *x* for *ch*) :—

"How I wish I could recollect of circle round
The exact relation Ar*x*imedes found."

VII. The age of the moon, from 0 to 30 days, is the sum of the day, month and year numbers. See rule on page 71, which is worth remembering.

VIII. The order in which sun, moon and planets pass through the constellations of the Ecliptic (called signs of the zodiac); and the order in which these constellations follow each other, nightly or monthly, is given by a doggerel on page 58, which is worth remembering.

IX. 24 sidereal hours=23 hours, 56 minutes, 4 seconds mean solar time.

X. The earth's radius=4000 miles. Multiply by 60 to get—
The moon's distance=240,000 miles.
The sun's distance=93,000,000 miles.

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* P.-M.=proper-motion.

APPENDIX II

DATA CONCERNING THE TWENTY-FIVE NEAREST STARS

Star	*Magnitude*		*Spectral Type*	*Distance lt.-yrs.*	*Annual Proper-Motion Seconds*	*Cross-Motion*	*Radial Velocity*
	Visual	*Abs.*				*Kilometres per second*	
Proxima Centauri	11·0	15·5	...	4·1	3·85	22·8	...
α Centauri . . .	0·3	4·7	Go	4·3	3·68	22·9	22·2
Barnard's star .	9·4	13·0	Mb	6·2	10·29	92·7	−80·0(?)
Lalande 21185 .	7·6	10·7	Mb	7·9	4·78	54·6	−87·0
Sirius	−1·6	1·3	Ao	8·6	1·32	16·4	−8·0
Anonymous . .	12	15	...	9·6	2·69	37·3	...
Cordova V 243 .	9·2	11·7	K2	10·2	8·75	129·0	+242·0
τ Ceti	3·6	6·1	Ko	10·2	1·92	28·3	−16·0
ε Eridani . . .	3·8	6·3	Ko	10·5	0·97	14·7	+15·6
Procyon . . .	0·5	2·9	F5	10·9	1·24	19·5	−4·3
61 Cygni . . .	5·6	8·0	K5	10·9	5·27	83·2	−64·0
Lacaille 9352 . .	7·4	9·7	Ma	11·2	6·90	112·0	+12·0
Pos. Med. 2164 .	8·8	11·1	Mb	11·2	2·31	37·4	...
ε Indi	4·7	6·9	K5	11·6	4·69	78·6	−38·7
Groombridge 34 .	8·1	10·3	Ma	11·6	2·89	48·5	+3·0
Krüger 60 . . .	9·3	11·4	K5	12·5	0·87	15·7	...
O.A.(N.) 17415-6	9·5	11·5	K	13·0	1·33	25·0	...
Anonymous . .	12·3	14·2	Fo	13·6	3·01	59·2	...
Altair	0·9	2·6	A5	14·8	0·66	14·1	−33·0
Gould 32416 . .	8·5	10·2	...	14·8	6·11	131·0	+26·0
Lalande 25372 .	8·5	10·1	K2	15·5	2·30	51·5	...
O_2 Eridani . .	4·5	6·0	G5	16·3	4·09	96·3	−41·6
W.B. XVI^h 1259	8·6	10·1	K8	16·3	0·37	8·7	...
O.A.(N.) 11677 .	9·2	10·7	Ma	16·3	2·99	70·4	...
W.B. X^h 234 . .	9·2	10·7	Md	16·3	0·49	11·5	...

In the third column, *Abs.* = Absolute magnitude, is the magnitude a star would show if it were at a distance of 32·6 light-years, where its parallax would be 0″·1.

In the fourth column, the spectral types (Harvard) are as given at p. 201.

APPENDIX TO CHAPTER XIV

MESSIER'S CATALOGUE OF NEBULÆ

Messier	*N.G.C.*	*R.A.* (1900·0)		*Dec.* (1900·0)		*Galactic Longitude*	*Galactic Latitude*	*Constellation*	*Description*
		hrs.	*min.*	*deg.*	*min.*	*deg.*	*deg.*		
1	1952	5	28·5	21	57	153	−4	Taurus . .	Crab Nebula
2	7089	21	28·3	−1	16	22	−37	Aquarius .	Globular Cl.
3	5272	13	37·6	28	53	8	77	Can. Ven. .	Globular Cl.
4	6121	16	17·5	−26	17	319	15	Scorpio . .	Globular Cl.
5	5904	15	13·5	2	27	333	45	Serpens . .	Globular Cl.
6	6405	17	33·5	−32	9	325	−3	Scorpio . .	Open Cl.
7	6475	17	47·3	−34	47	324	−6	Scorpio . .	Open Cl.
8	6523	17	57·6	−24	23	334	−3	Sagittarius .	Irregular Neb.
9	6333	17	13·3	−18	25	334	9	Ophiuchus .	Globular Cl.
10	6254	16	51·9	−3	57	343	22	Ophiuchus .	Globular Cl.
11	6705	18	45·7	−6	23	355	−4	Scut. Sob. .	Open Cl.
12	6218	16	42·0	−1	46	344	25	Ophiuchus .	Globular Cl.
13	6205	16	38·1	36	39	26	40	Hercules .	Globular Cl. (Hercules)
14	6402	17	32·4	−3	11	349	14	Ophiuchus .	Globular Cl.
15	7078	21	25·2	11	44	33	−29	Pegasus . .	Globular Cl.
16	6611	18	13·2	−13	49	345	−1	Scut. Sob. .	Open Cl.
17	6618	18	15·0	−16	13	342	−2	Sagittarius .	Omega Neb.
18	6613	18	14·1	−17	10	341	−1	Sagittarius .	Open Cl.
19	6273	16	56·4	−26	7	325	8	Ophiuchus .	Globular Cl.
20	6514	17	56·3	−23	2	335	−2	Sagittarius .	Trifid Neb.
21	6531	17	58·6	−22	30	336	−2	Sagittarius .	Open Cl.
22	6656	18	30·3	−23	59	338	−9	Sagittarius .	Globular Cl.
23	6494	17	51·0	−19	0	337	1	Sagittarius .	Open Cl.
24	6603	18	12·6	−18	27	341	−3	Sagittarius .	Open Cl.
25	{I. C. 4725}	18	25·8	−19	19	341	−5	Sagittarius .	Open Cl.
26	6694	18	39·8	−9	30	351	−4	Sagittarius .	Open Cl.
27	6853	19	55·3	22	27	29	−4	Vulpecula .	Dumb-bell Neb.
28	6626	18	18·4	−24	55	336	−7	Sagittarius .	Globular Cl.
29	6913	20	20·3	38	12	44	0	Cygnus . .	Open Cl.
30	7099	21	34·7	−23	38	356	−48	Capricornus	Globular Cl.
31	224	0	37·3	40	43	89	−20	Andromeda	Andromeda Nebula
32	221	0	37·2	40	19	89	−21	Pisces . .	Nebula
33	598	1	28·2	30	9	102	−30	Triang. . .	Spiral Neb.
34	1039	2	35·6	42	21	111	−15	Perseus . .	Open Cl.
35	2168	6	2·7	24	21	154	4	Gemini . .	Open Cl.
36	1960	5	29·5	34	4	142	2	Auriga . .	Open Cl.
37	2099	5	45·8	32	31	145	4	Auriga . .	Open Cl.
38	1912	5	22·0	35	45	140	2	Auriga . .	Open Cl.
39	7092	21	28·6	48	0	60	−3	Cygnus . .	Open Cl.
40	...	12	17·4	58	40	...	...	Ursa Major	Two faint stars
41	2287	6	42·7	−20	38	199	−9	Canis Major	Open Cl.
42	1976	5	30·4	−5	27	176	−18	Orion . .	Orion Neb.
43	1982	5	30·6	−5	20	176	−18	Orion . .	Irregular Neb.
44	2632	8	34·3	20	20	173	34	Cancer . .	Præsepe

MESSIER'S CATALOGUE OF NEBULÆ—*continued*

Messier	*N.G.C.*	*R.A.* (1900·0)		*Dec.* (1900·0)		*Galactic Longitude*	*Galactic Latitude*	*Constellation*	*Description*
		hrs.	*min.*	*deg.*	*min.*	*deg.*	*deg.*		
45	...	3	41·5	23	48	135	−23	Taurus . .	Pleiades
46	2437	7	37·2	−14	35	200	6	Puppis . .	Open Cl.
47	2478	7	50·2	−15	9	201	7	Puppis . .	Cluster
48	...	8	9·0	−1	39	192	29	Monoceros.	Very open Cl.
49	4472	12	24·7	8	33	259	70	Virgo . .	Nebula
50	2323	6	58·2	−8	12	190	0	Monoceros.	Open Cl.
51	5194	13	25·7	47	43	68	71	Canes Ven.	Spiral Neb.
52	7654	23	19·8	61	3	81	1	Cassiop. .	Cluster
53	5024	13	8·0	18	42	307	79	Coma Ber. .	Globular Cl.
54	6715	18	48·7	−30	36	333	−16	Sagittarius.	Globular Cl.
55	6809	19	33·7	−31	10	336	−25	Sagittarius.	Globular Cl.
56	6779	19	12·7	30	0	30	7	Lyra. . .	Globular Cl.
57	6720	18	49·9	32	54	30	13	Lyra. . .	Lyra-Ring Nebula
58	4579	12	32·7	12	22	259	75	Virgo . .	Spiral Neb.
59	4621	12	37·0	12	12	263	75	Virgo . .	Spiral Neb.
60	4649	12	38·6	12	6	265	75	Virgo . .	Nebula
61	4303	12	16·8	5	2	256	66	Virgo . .	Spiral Neb.
62	6266	16	54·8	−29	58	321	6	Scorpius .	Globular Cl.
63	5055	13	11·3	42	34	69	74	Canes Ven.	Spiral Neb.
64	4826	12	51·8	22	13	295	84	Coma Ber. .	Spiral Neb.
65	3623	11	13·7	13	38	209	64	Leo . . .	Spiral Neb.
66	3627	11	15·0	13	32	211	64	Leo . . .	Spiral Neb.
67	2682	8	45·8	12	11	183	34	Leo . . .	Open Cl.
68	4590	12	34·2	−26	12	268	35	Hydra . .	Globular Cl.
69	6637	18	24·8	−32	25	329	−12	Sagittarius.	Globular Cl.
70	6681	18	36·7	−32	23	330	−14	Sagittarius.	Globular Cl.
71	6838	19	49·3	18	31	24	−6	Sagittarius.	Open Cl.
72	6981	20	48·0	−12	55	3	−34	Capricornus	Globular Cl.
73	6994	20	53·5	−13	1	3	−36	Capricornus	Open Cl.
74	628	2	31·3	15	16	107	−46	Aries . .	Spiral Neb.
75	6864	20	0·2	−22	12	348	−28	Sagittarius.	Globular Cl.
76	650	1	36·0	51	4	98	−11	Persius . .	Gaseous Neb.
77	1068	2	37·6	−0	26	141	−52	Cetus . .	Spiral Neb.
78	2068	5	41·6	0	1	173	−14	Orion . .	Irregular Neb.
79	1904	5	20·1	−24	37	195	−28	Lepus . .	Globular Cl.
80	6093	16	11·1	−22	44	320	18	Scorpius .	Globular Cl.
81	3031	9	47·3	69	32	109	42	Ursa Major	Spiral Neb.
82	3034	9	47·5	70	10	109	42	Ursa Major	Spiral Neb.
83	5236	13	31·4	−29	21	283	31	Hydra . .	Spiral Neb.
84	4374	12	20·0	13	26	251	74	Virgo . .	Nebulous Spot
85	4382	12	20·4	18	45	243	80	Coma Ber. .	Nebula
86	4406	12	21·1	13	30	251	74	Virgo . .	Nebulous Spot
87	4486	12	25·8	12	57	256	74	Virgo . .	Nebula
88	4501	12	26·9	14	58	256	76	Coma Ber. .	Spiral Neb.
89	4552	12	30·6	13	6	260	75	Virgo . .	Nebula
90	4569	12	31·8	13	43	260	75	Virgo . .	Spiral Neb.
91	...	12	36·0	13	50	...	...	...	Probably a Comet

MESSIER'S CATALOGUE OF NEBULÆ—*continued*

Messier	*N.G.C.*	*R.A.* (1900·0)		*Dec.* (1900·0)		*Galactic Longitude*	*Galactic Latitude*	*Constellation*	*Description*
		hrs.	*min.*	*deg.*	*min.*	*deg.*	*deg.*		
92	6341	17	14·1	−43	15	35	34	Hercules .	Globular Cl.
93	2447	7	40·4	23	38	207	2	Puppis . .	Open Cl.
94	4736	12	46·2	41	40	76	86	Canes Ven.	Spiral Neb.
95	3351	10	38·7	12	14	201	57	Leo . . .	Spiral Neb.
96	3368	10	41·5	12	21	204	58	Leo . . .	Spiral Neb.
97	3587	11	9·0	55	34	114	57	Ursa Major	Owl Neb.
98	4192	12	8·7	15	27	234	75	Virgo . .	Spiral Neb.
99	4254	12	13·8	14	58	244	75	Virgo . .	Spiral Neb.
100	4321	12	17·9	16	23	246	77	Coma Ber. .	Spiral Neb.
101	5457	13	59·6	54	50	68	59	Ursa Major	Spiral Neb.
102	5866?	15	3·8	56	9	58	52	Draco . .	Spiral Neb.
103	581	1	26·6	60	11	96	−1	Cassiop. .	Open Cl.

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